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THESIS

**NAVIGATIONAL HEADS-UP DISPLAY: WILL A
SHIPBOARD AUGMENTED ELECTRONIC
NAVIGATION SYSTEM SINK OR SWIM?**

by

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March 2015

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ELECTRONIC NAVIGATION SYSTEM SINK OR SWIM?**

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ABSTRACT

The aim of this thesis is to develop and test a proof-of-concept augmented reality display that presents critical navigation information to naval conning officers. The objective of this research effort was to study the feasibility and usability of such an approach in operational conditions. The testbed platform consisted of a virtual environment that fully simulated a conning officer's basic tasks in conditions of restricted navigation; this type of setup enabled a cost-effective test solution that was safe and supported scenario repeatability in studies with human subjects. The study involved 25 experienced test subjects who were surface warfare officers at both the Naval Postgraduate School and Surface Warfare Officer School. This effort helped acquire a comprehensive set of objective and subjective data that provided a close insight into the performance of conning officers. The empirical results demonstrate the viability of using such a system in an operation environment and support a need for further research and development of a working display platform onboard Navy warships.

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LIST OF ACRONYMS AND ABBREVIATIONS

3D	Three-Dimensional
AIS	Automatic Identification System
AR	Augmented Reality
CNI	Critical Navigation Information
COG	Course over Ground
COVE	Conning Officer Virtual Environment
CRT	Cathode Ray Tube
DAS	Distributed Aperture System
DK1	Development Kit 1
DK2	Development Kit 2
DOD	Department of Defense
DOF	Degrees of Freedom
DTT	Distance to Turn
ECDIS-N	Electronic Chart and Display Information System—Navy
FMB	Full Mission Bridge
FOV	Field of View
FPS	Frames per Second
GUI	Graphical User Interface
GPS	Global Positioning System
HMD	Head-Mounted Display
HUD	Heads-Up Display
IP	Internet Protocol
IR	Infrared
LCD	Liquid-Crystal Display
LED	Light-Emitting Diode
LCS	Littoral Combat Ship
MOVES	Modeling, Virtual Environments and Simulation
MUVE	Multi-user Virtual Environments
NATO	North Atlantic Treaty Organization
NAVHUD	Navigational Heads-Up Display

NAVDORM	Navy's Navigation Department Organization and Regulations Manual
NPS	Naval Postgraduate School
OOD	Officer of the Deck
PID	Proportional Integral Derivative
RPC	Remote Procedure Calls
PTSD	Post-traumatic Stress Disorder
SDK	Software Development Kit
SOG	Speed over Ground
SWOS	Surface Warfare Officer School
USD	United States Dollar
USNS	United States Naval Ship
USS	United States Ship
VE	Virtual Environment
VMS	Voyage Management System
VR	Virtual Reality

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I. INTRODUCTION

A. RESEARCH DOMAIN

Despite the introduction of Global Positioning System (GPS) and electronic navigation, the art and science of conning a naval vessel has changed very little over the past half-century. Driving military ships is still a heavily manual practice and, since 1980, there have been over 100 navigation related mishaps significant enough to warrant formal investigation (Department of the Navy Naval Safety Center, 2014). As an example, in February of 2013, USS Guardian (a minesweeper forward deployed to Japan) ran aground in the Philippines. This incident not only caused irreparable damages to the local reef system, but resulted in the complete loss of the vessel (U.S. Pacific Fleet Public Affairs, 2013). In July 2000, a collision at sea between USS Denver and USNS Yukon resulted in the former receiving “a gaping 40-foot hole in the bow from the second deck to the waterline” (Doehring, 2014). In September of the same year, USS La Moure County ran aground off the coast of Chile, receiving damages significant enough to warrant decommissioning and later scuttling (Doehring, 2012). While there are always numerous contributing factors to groundings and collisions, the fact that these incidents continue to occur clearly indicates a need for more effective solutions and tools to assist navigation tasks.

If the U.S. Navy continues the historical trend of having its officers manually drive ships, then every effort to augment human capabilities and incorporate current sensor technologies into the decision-making loop must be made. The electronic sensors on ships already collect and process enough data to make safer navigation a reality. It is an efficient presentation of that information to the human operator that is lacking; a real-time visual display system always accessible to conning officers and in their visual field of view (while still allowing them to focus on the visuals of the real world in front of their eyes) has yet to be developed. If such a system is to be adopted on future ships and serve the needs of conning officers, it must be: relatively cheap, absolutely reliable, robust, rugged, and highly effective at relaying the navigational picture to the human operator.

B. MOTIVATION FOR RESEARCH

(1) Navigation Mishaps are Costly

Since 1980, over 8 percent of the total number of Class A and Class B mishaps that occurred in the Navy have been navigation related (Department of the Navy Naval Safety Center, 2014). The Office of the Chief of Naval Operations defines Class A and Class B mishaps as follows (Office of the Chief of Naval Operations & Commandant of the Marine Corps, 2005, p. 2–2)

Class A Mishap. The resulting total cost of damages to DOD or non-DOD property in an amount of \$2 million or more; a DOD aircraft is destroyed; or an injury and/or occupational illness result in a fatality or permanent total disability.

Class B Mishap. The resulting total cost of damages to DOD or non-DOD property is \$500,000 or more, but less than \$2 million. An injury and/or occupational illness result in permanent partial disability or when three or more personnel are hospitalized for inpatient care (beyond observation) as a result of a single mishap.

Although the incidents only average to three per year, each accident is a significant event with strategic consequences (Department of the Navy Naval Safety Center, 2014). In the case of USS Guardian, (one of only a few remaining mine-countermeasure ships) the U.S. Navy lost a significant percentage of its capability to hunt and disable mines. With each new naval platform being more robust and more costly, the loss of only a few ships to causes such as preventable navigation mishaps cannot be afforded.

(2) Current Practices are Error Prone

Methodology of how ships are driven in today's environments is detailed in Chapter III. In general, the navigation evaluator gives directions to the conning officer, who then orders the helmsman to manipulate the ship's rudder and engines. This communication path requires constant alertness of all parties and complete focus on the task. If communications are misunderstood or misinterpreted, the ship can be driven into dangerous waters that put the entire crew at risk. Minor variables such as personal accents, vocal inflections, or sickness can negatively impact the effectiveness of these

communications. External forces such as machinery noise, heavy rain, or adjacent traffic can also induce errors in understanding the reports or orders. The helmsman is trained to repeat back his orders to the conning officer before execution, with the goal of mitigating some of these issues; however, the reports and recommendations from the navigation evaluator are not repeated. Given all these issues, the overall procedure for navigation through restricted waters can and should be improved.

C. RESEARCH QUESTIONS

The following research questions are the focal points in this thesis:

- Does replacing the auditory inputs from the navigation officer with an augmented field of view (FOV) that visually feeds critical navigation information (CNI) to the conning officer aid or hinder his performance?
- If a heads-up display (HUD) system was designed and deployed to the fleet, would surface warfare officers be receptive to the idea of integrating and using such a system in their daily operations?

D. HYPOTHESES

For the purpose of this thesis research, the following two null hypotheses and alternative hypotheses have been established:

(1) Hypothesis 1

- Null Hypothesis: $H1_0$ —A lightweight, glasses-type augmented reality (AR) overlay system for a conning officer does not increase his ability to maintain a close proximity to a preplanned track.
- Alternative Hypothesis: $H1_A$ —A lightweight, glasses-type AR overlay system for a conning officer will increase his ability to maintain a close proximity to a preplanned track.

(2) Hypothesis 2

- Null Hypothesis: $H2_0$ —The surface warfare officers will not be receptive to the idea of integrating and using such a system into their daily operations
- Alternate Hypothesis: $H2_A$ —The surface warfare officers will be receptive to the idea of integrating and using such a system into their daily operations

E. SCOPE

The scope of this thesis will be to study the effectiveness of an AR overlay for conning officers in the situation of an outbound channel transit with no traffic or navigation aids in the adjacent water. The purpose of not including surface vessel traffic in the simulation was to reduce the number of variables in the experiment. Just as there are numerous methods to driving ships, so too are there methods to dealing with oncoming surface traffic. While the best way to test such a system would be going to a physical ship with a commercial off-the-shelf hardware prototype, there are numerous safety and repeatability concerns that make such testing unrealistic. Therefore, our decision was to conduct all tests in a fully immersive three-dimensional (3D) virtual shipboard environment via a head-mounted display (HMD).

The computer supported simulation will allow us to: present the same system conditions and scenario to a human operator, capture a precise objective data set related to the operator's performance, and to complete that test with utmost safety provided to the subjects. Virtual environments have been proven as effective testbeds capable of simulating and studying the real shipboard operations; this in turn suggests that the results acquired in this study will indicate the system's applicability and relevance to the real-world situations (de Moraes, 2011).

F. THESIS CONTRIBUTIONS

This thesis will provide empirical data on the usefulness of AR concepts for conning officers. Questionnaires and interviews were used to capture study subjects' opinions on the operational usefulness of such a system. These opinions come from experienced officers who represent the community of shareholders who may end up using this technology in the near future. The technical discussion of how to best design the layout for the augmented layer is also provided. Creating a HUD that was able to provide ample information while not being overly distracting was a critical goal of the study. The study design balanced all experimental and domain requirements, and the final results were documented after conducting analysis of tracking data and questionnaires.

G. THESIS STRUCTURE

Chapter I is an introduction of the overall goals and methods of the study.

Chapter II details a collection of background information covering both the doctrine and the technology employed onboard today's ships. Additionally, this section contains a literature review on the topics and issues related to VR and AR systems.

Chapter III presents a description of daily responsibilities of those in charge of the navigation of a ship.

Chapter IV details the environment used for the user study. This covers both the technical hardware descriptions as well as describing the process of creating the virtual testing environment.

Chapter V covers the entirety of the usability study and data analysis.

Chapter VI offers a conclusion and several insights into recommendations for future work.

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II. BACKGROUND

This chapter provides background knowledge of the operational, technological, and physiological models directly related to the thesis research domain and consequently used in the development and testing of the Navigation Heads-up Display (NAVHUD) system. The chapter covers the doctrinal policies of U.S. Navy restricted maneuvering operations. Additionally, the section provides a literature review of the VR and AR fields. Finally, the physiological phenomena associated with virtual environments (VE) are discussed. This chapter provides only a rudimentary evaluation of each of these domains, offering enough information for the reader to comprehend the experimental design and execution.

A. RESTRICTED MANUEVERING

The starting goal for the study was to limit testing of the NAVHUD system to conditions that made sense operationally, and thusly a decision to only cover restricted maneuvering situations was adopted. Restricted maneuvering is an operational term used for situations when the ship is restricted in its ability to maneuver either due to environmental or operational reasons. The seminal text for newly reporting surface warfare officers defines four specific conditions for which the ship is considered in restricted maneuvering (Stavridis & Girrier, 2007, p. 329):

1. Operating in restricted waters
2. Steaming in close formation
3. Conducting an underway replenishment
4. Engineering casualties affecting the ship's ability to maneuver

The focus of this work is the most common of these situations—operations in restricted waters. Several actions must be taken by the ship's crew for any of the four conditions. Firstly, several additional bridge and engineering watches must be stood up. This is intended to not only provide greater accuracy of maneuvering but to also provide an immediate reaction capability in the event of any casualties. Additionally, the

engineering plant is required to be configured in a maximum reliability lineup (Stavridis & Girrier, 2007, p. 329). Although the actual definition of maximum reliability differs for each ship, this process normally involves bringing all the main engines online, preparing supplemental generators for immediate use, testing the after steering controls, and manning additional engineering watches. The purpose of these acts is to provide maximum capability to individuals driving the ship from the bridge.

(1) Bridge Team

When steaming in open ocean (more than 10 nautical miles from land) and not conducting operations, the bridge of a U.S. warship can have as few as three personnel on watch: the officer of the deck (OOD), acting as primary supervisor and doubling as a conning officer; the helmsman controlling the ship; and a quartermaster, acting as the navigation department representative. This watch configuration changes dramatically when conducting restricted maneuvering operations. With as many as 20 personnel standing critical bridge watch positions, only the roles of those who are primarily tasked with the safe navigation of the ship will be detailed.

- OOD: The primary supervisor for all watch stations, the OOD is the captain's direct representative on the bridge. Tasked with the safe execution of naval operations, the OOD is overall responsible for the safety of the ship and crew.
- Conning Officer: The conning officer is tasked with the physical maneuvering of the ship. By issuing engine and rudder orders to the helmsman, the conning officer drives the ship. He combines the recommendations provided by the navigation evaluator, and the current surface contact picture, to keep the ship safe from collisions and groundings.
- Helmsman: The helmsman takes the orders of the conning officer and turns them into physical actions. The helmsman does not make independent decisions on when to turn or what course to come to. Rather, he provides a logical safety barrier for situations where the conning officer may give an incorrect order.
- Navigation Evaluator: The navigation evaluator is responsible for reporting where the ship is currently positioned. Comparing several sources available to him, the navigation evaluator can make a precise determination of the ship's position. With this information, the navigation

evaluator recommends courses to the conning officer that will keep the ship in safe water.

(2) Restricted Waters

Defined as waters that are less than two nautical miles from land or shoal water, restricted waters are transited on a daily basis by U.S. Navy warships (COMNAVSURFPAC et al., 2013). While the most common transits of restricted waters are entering and exiting ports, there are many other cases where a vessel might be required to come within two miles from land. These include coastal patrols, strait transits, minesweeping operations, or even rendering assistance to distressed mariners. In all cases where the ship enters restricted waters, the ship is required to stand up the watches and engineering plant configurations associated with restricted maneuvering operations.

B. CURRENT TECHNOLOGICAL ENVIRONMENT

The U.S. Navy has invested heavily in the research and development of technologies that aid in the safe navigation of its ships. The following systems are used on a daily basis to track surface contacts, communicate with merchant vessels, and plan navigation transits.

(1) Radar

There are numerous commercial and military radar systems installed on today's Navy ships. These include navigation radars, surface search radars, and air control radars (U.S. Navy, n.d.). These systems give the U.S. Navy the capability to create an operational picture of what vessels and aircraft are maneuvering in the area. Using this information, the ship's crew can prevent collisions by anticipating the movements of nearby traffic.

Although primarily associated with the discovery and classification of air and surface contacts, radar is also a useful mechanism for indicating where the land is. The radio waves bounce off of any surface that protrudes out of the water and that information is relayed in a visual format to the radar operator. When used in conjunction with nautical charts, these radar readings can help determine the precise location of the ship. This capability is critical in cases where GPS satellite signals are lost.

(2) Automatic Identification System

Automatic Identification System (AIS) is a system that uses GPS to track and display ocean vessels. The system is an international standard that is used by nearly all large commercial shipping traffic. U.S. Title 33, Code of Federal Regulations requires all tankers, all vessels certified to carry over 150 passengers, and all ships over 300 gross tons to have the system installed and activated (U.S. Coast Guard Navigation Center, 2015). This policy is enforced by the U.S. Coast Guard. The data collected by the system is overlaid onto an electronic chart display and information system. The system displays vessels as symbols which can be selected to show more information about any specific ship. AIS keeps a record of the vessel name, call sign, voyage plan, maneuvering information, and other data that can be used by mariners. Oftentimes, AIS is used by the U.S. Navy to find surface contacts before radar can reach them. The inclusion of call signs in the system lets mariners contact each other over the radio and arrange safe passage.

(3) Electronic Chart Display and Information System

Electronic Chart Display and Information System—Navy (ECDIS-N) is the U.S. Navy's primary shipboard navigation tool (Chief of Naval Operations, 2001). Overlaying the ship's own internal sensors and AIS data onto National Geospatial Agency released digital nautical charts, navigation officers are provided a real-time picture of what is proximate to the ship. This same system enables the navigation team to plan and execute transits with great precision. By placing waypoints into the system, a safe transit that avoids land and shoal water is created. When the ship executes these transits, the system provides constant guidance of how to maintain and regain the planned track.

A key feature of the system is the digital chart correction component. Whereas with paper charts, ship personnel were required to read lengthy reports and manually draw in corrections on the charts, the ECDIS-N system allows for instant importation of chart updates. This not only ensures consistency in the chart updates, but also saves many man-hours related to chart corrections.

C. VIRTUAL TESTBED TECHNOLOGY

1. Virtual Reality

Professor Frederick P. Brooks, Jr. defines a virtual reality (VR) experience as “any in which the user is effectively immersed in a responsive virtual world” (1999, p. 16). Additionally, Bryson (1996, p. 62) specifies the need to create worlds “in which the user interacts directly with virtual objects.” Any definition given by subject matter experts will cover a broad category of applications; however, the general consensus is that VR has an experiential, rather than technological, focus designed to draw the user out of the real world and place them into a virtual one (Steuer, 1992).

While modeling and simulating tasking can never fully replace the true physical undertaking, there is ample evidence of the power and capability that VR technology brings to the realms of training and operational testing. Today’s VR systems are being used in the fields of education, entertainment, industry, architecture, cultural heritage, medicine, psychology, and even the military. As an example, VR studies and applications have been used to treat phantom pains in amputee victims, soothe burn victim’s pain during recovery therapy, assist disabled patients with physical therapy, and even provide treatment to soldiers suffering from post-traumatic stress disorder (PTSD) (Casti, 2014; Rizzo, Difede, Rothbaum, Daughtry, & Reger, 2013; Yano, Tamefusa, Tanaka, Saito, & Iwata, 2012; Rothbaum et al., 1999). Additionally, VR has allowed surgical students to practice their operating room techniques and has even given autistic children a medium in which they can better learn social and motor skills (Casti, 2014; Maskey, Lowry, Rodgers, McConachie, & Parr, 2014; Seymour et al., 2002).

Interactive 3D video games are the best examples of VEs that allow multiple users to control characters and character-based interactions within the virtual space. Beyond simple entertainment, multi-user virtual environments (MUVE) have been shown to support teaching and learning. As an example, Harvard University’s “River City is a MUVE for teaching scientific inquiry and 21st-century skills in middle school science classes” (Dieterle & Clarke, 2007, p. 2). This system has been proven to allow for the

monitoring and assessing of individual students far better than the traditional teaching systems.

2. Augmented Reality

Whereas VR attempts to fully encompass users in a VE, AR attempts to display only elements of the VE to the users. To describe AR is to describe a technology that “supplements the real world with virtual (computer-generated) objects that appear to coexist in the same space as the real world” (Krevelen & Poelman, 2010, p. 1). Just as in VR, this is accomplished by the use of special display solutions such as headsets, display monitors, and programmable glass. The critical requirements for an AR system are: combining real-world objects with virtual overlays, properly aligning those objects, and being interactive in real-time (Krevelen & Poelman, 2010). Additionally, true AR systems must be registered in three dimensions (Azuma, 1997).

With exception of the overlay requirement, these rules apply to VR just the same. The difficulty in AR however comes from alignment, i.e., registration of components of virtual and real world. While VEs are fully defined in their shape, size, colors, textures and behaviors; the ability to align virtual objects precisely over the (unknown) real world is a non-trivial matter. A relaxed definition of AR removes the difficult factor of alignment. Instead, the augmented layer can simply overlay the user’s visual field with digital information, ignoring the need to track any real-world objects.

As display technologies and computers become faster and cheaper, AR will become more useful. The concept of utilizing AR in the maritime domain is not unprecedented. There already exists patents for such systems; more specifically there is one for a “Wearable marine heads-up display system” that outlines many of the ideas presented in the Chapter I (U.S. Patent No. 20070030211 A1, 2006, p. 1). Military use of AR is also not unique as the newest fighter aircraft, the F35 Lighting, features an AN/AAQ-37 Distributed Aperture System (DAS). This video-see-through headset system allows the pilot to not only look down through the physical cockpit onto the ground, but also displays a clear bright landscape at night and can simultaneously overlay target acquisition data (Northrop Grumman, n.d.). With military AR systems already being

utilized in real-world operations, acceptance of such technologies in other domains, such as shipboard navigation, may follow the same adoption path.

3. Head-Mounted Displays

VR technology has been around for more than four decades and during that time VR systems have used a rich variety of visual display solutions. The recent boom in cell phone technology has allowed engineers to begin bringing VR to the consumer market through cheaper and more effective head-mounted displays (HMD). These HMDs are “interactive head-referenced computer displays that give users the illusion of displacement to another location” (Ellis, 1994, p. 17). Depending on the level of haptic sensory information and modality of user interaction within the system, the environment can allow user interaction with the virtual objects comparable to interactions one would have in the real environment. The trends of increased wireless availability, miniaturization of electronic sensors, and higher resolution display technology are collectively allowing HMDs to be used in our daily lives. (Cakmakci & Rolland, 2006)

As a system, HMDs comprise of several components. The following is a description of each of the key mechanisms that make up an HMD.

(1) Display

The primary visual component of a HMD is the display. Older hardware used miniature monochrome cathode ray tube (CRT) displays but they tended to be heavy, large, and required significant power to run (Patterson, Winterbottom, & Pierce, 2006). Today’s displays utilize liquid-crystal display (LCD) and light-emitting diode (LED) panels making them lighter, smaller, and less power intensive.

An important distinction between HMD displays is the field of view (FOV) that they offer. The average human has a natural FOV of “200° horizontal by 130° vertical, with the central 120° being the area of binocular overlap” (Patterson et al., 2006, p. 562; Velger, 1998, p. 50; U.S. Department of Defense, 1962). This large FOV is not necessary to replicate for all applications but for realistic environment trainers, the display should provide as close to human peripheral vision as possible (Cakmakci & Rolland, 2006).

The commercial displays available today offer FOV that range from 100° to 164° horizontal and up to 60° vertical (Sensics, n.d.; Oculus VR, n.d.).

Other critical components of the display are luminance and resolution. Both of these elements provide the HMDs with the capability to render images that are clearly visible with high contrast (Patterson et al., 2006). Luminance is determined by the display material (CRT, LCD, LED) and can range from 5,000 fL to 12,000 fL for high-end displays (Velger, 1998). Resolution is immediately perceived in the display due to the proximity of the eye to the screen when wearing an HMD. Today's LED screens allow for up to 1920×1200 pixels per eye (Sensics, n.d.).

(2) Head Tracking

Tracking the rotation of the user's head is a significant characteristic that separates HMDs from simple monitors or televisions. When a human moves and rotates their head in any direction, the eyes are presented with a new view. To replicate this effect, VR systems track head position and rotation about the X, Y, and Z planes. General head tracking can also include positional tracking which provides a full six degree of freedom (DOF) for the user. The rendered scene will shift in correlation with the head movement. The level of tracking precision for a system determines if minute shifts in the head's position are represented in the scene. In addition to precision, the latency of tracking updates is a considerable issue that affects every HMD design. Delays in rendering the scene with respect to the head tracking data can cause significant health issues including cybersickness, which is covered later on in this chapter (Patterson et al., 2006).

(3) Frame

The frame of the HMD is an ergonomic consideration, particularly with regards to its weight. As a device for research, training, or entertainment, HMDs are being designed for extended use. The effects of cybersickness aside, discomfort from the weight of the headset can be a limiting factor to the user experience. Prolonged exposure to excessive weight on the head can cause shoulder and neck irritation. Additionally, because fully enclosed HMDs completely cover the face, heat can build up and cause

sweating or fogging of the lenses. Excessive sweat in the mask is a sanitary issue that needs to be addressed if conducting subject testing with HMDs.

4. Testing and Measuring Performance

While AR and VR do offer a wide range of possibilities to several domains, there still exist several critical areas of study within these technologies that have yet to be fully understood. These include testing and measuring human performance, measuring sense of presence, measuring navigational complexity of the environment, and estimating distances in VEs. Each of these issues has been researched in depth, but just as every AR or VR system has a particular combination of different technical characteristics and capabilities that are unique, so too are the effects they may have on human operators. What is important to take away is not a “one-size-fits-all solution” on how to accommodate for these issues, but rather a general understanding of what to look for when designing such systems. With that in mind, the first topic to be discussed will be the testing and measuring of human performance.

(1) Benchmark Performance

One of the most difficult aspects of testing and evaluating the effectiveness of any virtual system is how to define good performance measurements and accurately collect them. Before any testing or performance measurements begin, one has to be reminded of the results supported by numerous studies in the domain of learning and training, “Some tasks may be uniquely suited to virtual representation while others may not be effectively performed in such environments.” (Stanney, Mourant, & Kennedy, 1998, p. 330). To even begin measuring the effectiveness of a VE, one must ascertain a means to assess the human performance in the virtual world. (Stanney, et al., 1998) Given that requirement, there are three major factors that are found to influence human performance in VR (shown in Figure 1): (1) Navigational complexity, (2) presence, and (3) benchmark performance (Stanney et al., 1998). Benchmark performance is a unique measurement determined by the application and the user’s baseline capabilities. More interesting are the variables of navigational complexity and presence which can be manipulated.

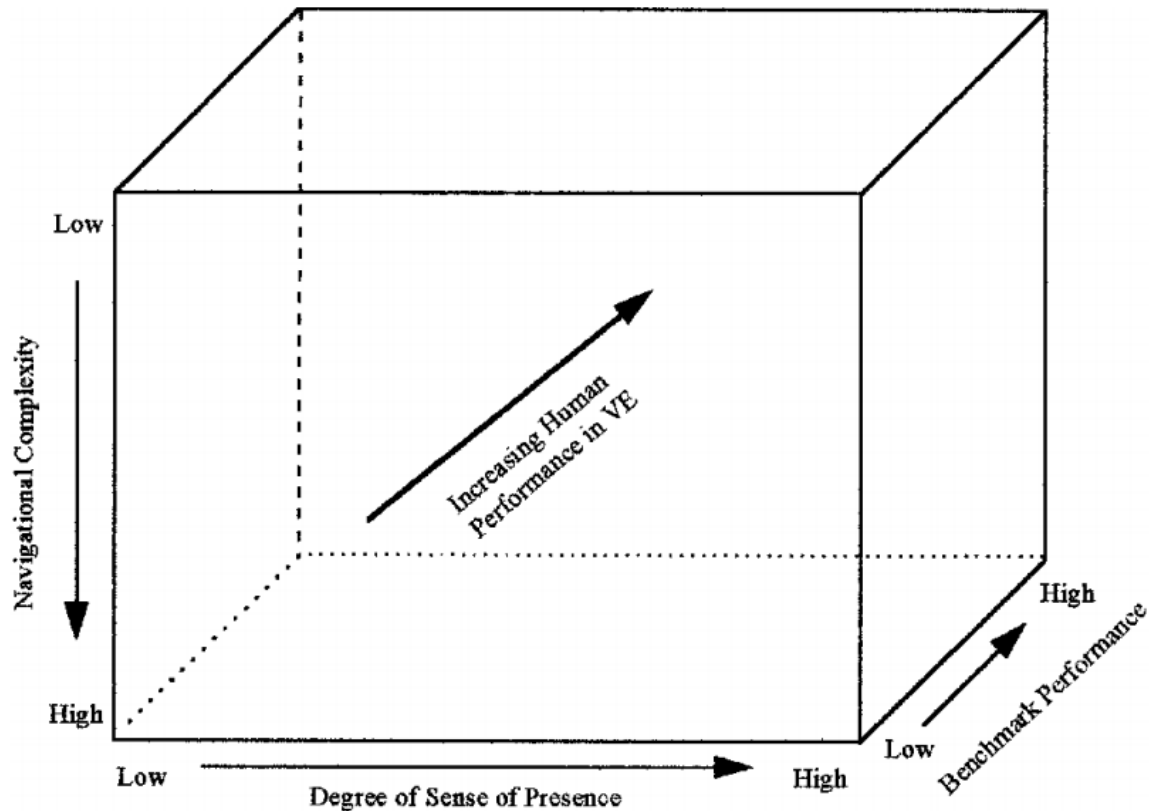


Figure 1. “Components of Human Performance in Virtual Environments”
(from Stanney et al., 1998, p. 329)

(2) Measuring Presence

“Presence is defined as the subjective experience of being in one place or environment, even when one is physically situated in another” (Witmer & Singer, 1998, p. 225). While some proponents focus on the visual stimuli of these environments, many researchers counter that presence is more about the user being able to do things; arguing that “the VE becomes endowed with ‘there-ness’ through this process of action and interaction” (Slater & Steed, 2000). The consensus among researchers in this domain suggests that presence is not an empirical factor that can be easily measured. The same researchers propose different means to measure this phenomenon. For example, reflexive responses, a three-attribute subjective category rating scale, and measurement based on discrimination are all methods suggested by Sheridan (1994). Slater and Steed suggest adding understanding “based on data that can be unobtrusively obtained during the course

of a VE experience” (2000, p. 413). Slater extends this further by codifying another contributing factor to presence. This factor is one he calls “Plausibility Illusion” referencing that users in a VE actually believe that the scenario they are experiencing is really happening (2009). Additional measures have been obtained using different sensors that determine physiological responses of a human operator (Meehan, Razzaque, Whitton, & Brooks Jr, 2003). In their work on measuring the effects of latency on presence in stressful VEs, they measured heart rate and skin conductance. Given the numerous definitions or measurements being used to study the field of VR, it is surprising that such things have not been standardized. As such it will continue to be the individual responsibility of researchers to maintain awareness of current practices.

(3) Measuring Navigational Complexity

In measuring navigational complexity in their seminal study on navigating VEs Usoh et al. used the factors of “How Simple?”; “How Straightforward?”; and “How Natural?” to score the ease of locomotion (1999). Navigation through the environment is determined by the mechanism of modality. Whether it is full motion tracking via sensors, a multidirectional treadmill, or even a game controller; users must be trained on the proper method to move about the scene. As walking is a natural task for humans, it is one of the least complex navigational methods. Tracking users as they walk through the physical environment has been proven to significantly increase their level of presence in the VE (Usoh et al., 1999). Unless highly familiar with the system, when users are required to use devices such as game controllers to maneuver their position in the VE their cognitive processing is split. This split disrupts the user’s ability to be immersed in the VE, thus lowering their overall performance.

(4) Estimating Distance in Virtual Environments

Studied extensively, the cognitive issue of estimating distances in VEs is currently a serious limitation of VR, especially in situations when this will influence basic task performance. Whereas humans can effectively estimate distances out to 20 meters, doing so when immersed in a VE is challenging and thus less accurate (Thompson et al., 2004). Depending on the purpose of the simulation, being able to develop spatial cognition of

the scene may be necessary. Researchers agree that accurately estimating distance is necessary to form an accurate mental model of the environment (Popp, Platzner, Eichner, & Schade, 2004; Witmer & Kiline, 1998). It is for this reason that studies have been conducted to understand why estimation of distance in VR is difficult.

Judging the distance of an object in VR usually requires that the subject be familiar with the relative size of a similarly shaped object. Studies have shown, however, that “changes in object size may be misinterpreted as changes in distance and vice versa” (Witmer & Kiline, 1998, p. 146). The causation for this issue is not isolated to just one factor and thus there is no agreement from researchers as to the underlying fundamental reason why distance estimation is so difficult in VR. Poor resolution, low FOV angles, inadequate tracking, and binocular depth cues are all contributing factors to this problem.

One proposed method for increasing the ability to estimate distances in VR is by rendering a “fully-articulated and tracked visual representation” of the user (Mohler, Creem-Regehr, Thompson, & Bulthoff, 2010, p. 230). By increasing the correlation with an avatar in the VE, users were able to more successfully judge the environment around them. This is an important discovery which compliments the findings by Thompson et al. that increasing the graphic fidelity alone does not necessarily increase distance estimation capabilities (2004). The final solution for giving humans the capability to accurately estimate distance in VR will likely come from integrating a combination of multiple techniques.

5. Health and Safety Considerations in Virtual Reality Systems

(1) Cybersickness

Thus, far, the discussion has been relegated to the technical characteristics and performance characteristics of VR and AR. Another critical aspect of these fields is the health and safety issues associated with research in these domains. These include things such as cybersickness, simulator sickness, cognitive tunneling, and other physical safety concerns. The rest of this chapter will focus primarily on the effects and causations of cybersickness as well as other safety concerns.

Commonly associated or confused as motion sickness, cybersickness is a direct byproduct of VR development. While sharing symptoms of nausea, drowsiness, headaches, disorientation, fatigue, and many more, the cause of cybersickness is different than that of simulator sickness (Stanney, Kennedy, & Drexler, 1997). Whereas vestibular stimulation by itself can cause simulator sickness, cybersickness can be brought on solely with visual stimulation. (LaViola, 2000). Given these differences, a clear line has been drawn between the two but the underlying causations of each are very similar. The standard theory of causation for motion sickness from VR simulations is suggested in the sensory-conflict theory (Cobb, Nichols, & Ramsey, 1999). “Sensory-conflict theory proposes that symptoms occur as a result of conflict between signals received by the three major spatial senses: the visual system, the vestibular system, and nonvestibular proprioception” (Cobb et al., 1999, p. 170). To simplify, the human body gets sick because the brain cannot process the differences between what it is seeing and feeling. This leads to vestibular instability, visual fluxes, and other physical manifestations. No matter the cause, the symptoms outlined above tend to last less than a couple of hours and have not been proven to cause long-term harm.

There are several specific influences that have been proven to raise the chances of cybersickness. For instance, female subjects are more at risk than men due to their wider FOV which increases flicker perception. (LaViola, 2000) Another significant factor that is relevant to any future study in shipboard navigation would be speed. Testing has shown that “vection sensation and sickness symptoms increased with increasing navigation speeds from 3m/s to 10m/s” within the simulation (So, Lo, & Ho, 2001). Vection in this situation is defined as “visually induced illusory self-motion” (Hettinger, Berbaum, Kennedy, Dunlap, & Nolan, 1990, p. 171). Being one of the direct causations of sensory-conflict it must be taken into account in motion platform systems. As any simulation allowing for shipboard navigation will include speed changes ranging from 0 to 15 m/s, vection must be a consideration at the design stage.

(2) Cognitive Tunneling

Commonly associated with AR applications, cognitive tunneling can be a serious health and safety threat to AR users. Cognitive tunneling is defined as the effect in which

a user focuses attention on a specific visual sector and therefore loses peripheral focus on other visual elements (Thomas & Wickens, 2001; Dowell, Foyle, Hooey, & Williams, 2002; Crawford & Neal, 2006). The result is a distracted user who loses focus of the overall task. In aviation, cognitive tunneling has been associated with pilots who focus on data readings in their HUD rather than the environment around them (Dowell et al., 2002). In automobiles, the effect can be seen by drivers paying attention to CD players, GPS, and other systems rather than the road in front of them (Olsson & Burns, 2000). Although not guaranteed to occur, cognitive tunneling must be accounted for when integrating AR into existing systems.

(3) Other Safety Issues

Beyond the issue of cybersickness, there are other safety considerations that must take place when working with VR, and especially with an HMD. The first lies with the physical hardware. Heavy and bulky headsets with prolonged usage are known to cause discomfort to subjects and can cause adverse effects on the experiment's results (Cobb, Nichols, & Ramsey, 1999). Cable management can also be a significant factor. By using headsets with tethered cables, subjects can become entangled and trip, causing not only harm to the subject, but also possibly negating results in the simulation or damaging equipment. On that same note, space allocation is another critical component to running experiments in VR. "Obviously, HMD use should not take place in areas where there are any hazardous objects or substances as the participant is unable to see their real-world surroundings and may be at risk of injury" (Cobb et al., 1999, p. 183). Overall, it is a combination of physical and physiological health issues that must be taken into consideration when working with VR or AR.

D. SUMMARY

This chapter has covered multiple domains ranging from military operations to academic research in the fields of VR and AR. With all of these topics being researched well ahead of the design stage of the study, many of the pitfalls associated with VR and AR applications were taken into consideration. The analysis of the literature helped to craft a better experience for the test subjects; some of these decisions included the way a

HUD layout was manipulated to reduce cognitive tunneling and the adjustment of the ship's speed to prevent cybersickness.

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III. DESCRIPTION OF SHIP NAVIGATION RESPONSIBILITIES

This chapter details the roles, responsibilities, and tasks performed by the primary individuals associated with the operation of safe navigation of a U.S. Navy warship. While there are many other critical members of the navigation team on the bridge, this chapter focuses on the roles of helmsman, navigation evaluator, and conning officer. Each of these individuals has his own unique duties to perform. When their tasks are well integrated and well executed, the combined performance results in the safe navigation of the ship. While no two ships within the U.S. Navy operate in exactly the same manner, these three roles are largely standardized throughout the fleet to deliver safe navigation.

Driving warships in today's complex tactical environments requires highly skilled personnel. Whether avoiding unmarked fishing buoys, maneuvering for air operations, or maintaining tactical formations; the basic tenants of driving warships apply to every size of vessel in the Navy's collection. While there are a number of situations where the members of the bridge team must complete specific event-dependent tasking, the study we conducted focused on three members of the bridge team during a routine channel transit. The reason the study focused on this situation is because restricted water navigation relies heavily on the skills of the conning officer and the doctrine for these operations is thoroughly documented. Therefore, the following sections outline the general tasks and expectations of each of these members during such a transit.

A. RESPONSIBILITIES OF A HELMSMAN

An important member of the bridge team, the inclusion of the helmsman during testing amplified the realism of the study and enabled the subjects to drive the ship as they would in real life. Whereas the tasks required of the navigator and conning officer have changed slightly with technology advancements, the job of the helmsman has remained constant: he "steers the ship as directed by the conning officer" (Cutler, 1998). The standardized method of completing that tasking is a multi-step process.

1. Repeat back order as given (verbatim)
2. Shift rudder according to order

3. Report the status of the rudder once it is in position
4. Manipulate the rudder so that the ship's heading matches the ordered course
5. Report that the ordered course has been met
6. Maintain the ordered course

There are many special circumstances in which the steps differentiate; however, the general list of steps that we provided accounts for most situations. Whereas there is always a helmsman at the helm while the ship is at sea, it is common practice to put the best and most experienced helmsman on the bridge team during a restricted maneuvering situation. This is because restricted maneuvering requires precision ship driving, loud and clear repeat-backs, and the capability to instantly take corrective actions in cases of emergency.

A helmsman's skill is not only determined by quick translation of commands to actions, but also by the ability to maintain a steady course. The addition of winds and currents are what differentiate driving a ship from driving a car. Whereas a well-aligned car can maintain its direction on a straight road, the helmsman must constantly make minor rudder adjustments to maintain course. In the case where the ship is being pushed significantly, more action is required by the helmsman.

Generally, there are limits placed on how much rudder the Helmsman can use without first getting permission from the Conning Officer. For example, in most cases, no more than ten degrees rudder in either direction is allowed without first requesting permission from the Conning Officer. The primary reason the Helmsman would need to use more than ten degrees rudder to maintain a course is a high sea-state. In this case, the Helmsman requests permission to use more than ten degrees rudder to maintain course. The Conning Officer would likely grant permission, and then the Helmsman would be free to use the rudder as required. (Norris, 1998, p. 96)

Although most of the actions of a helmsman are scripted, it is also the helmsman's job to ensure (check) that orders given to him do make sense. An example would be for the conning officer to give a left rudder command for a course that is nearer to starboard. While this is indeed a legitimate order that can be executed, it is more likely

that the conning officer simply made a mistake. It is during these points that the helmsman would attempt to seek clarification by asking “Orders to the helm?” During a channel transit with many quick successive turns it is important that the helmsman be able to not only focus on the precise handling of the ship but to also smartly interpret the commands being given to him.

While ship driving practices are changing in the U.S. Navy’s newest generation of ship, the nature of how the bulk of the U.S. fleet operates at sea demands that the position of helmsman be filled for many years to come (Ewing, 2008). It is a combination of their quick reaction capabilities and a practiced skillset of handling casualties that makes the helmsman such a vital part of the bridge team. It is for this reason that including the helmsman in the study was required.

B. RESPONSIBILITIES OF A NAVIGATION EVALUATOR

A critical portion of the study replicated the everyday interactions between conning officer and navigation evaluator. In order to make a baseline determination of how well conning officers perform in the current operational environment, it was essential to include a navigation evaluator as well. Usually performed by the ship’s navigation officer, the position of navigation evaluator is an important role that is responsible to the commanding officer for the safe navigation of the vessel. This responsibility is so great that, in the event of extreme danger, “the navigator may be authorized by the captain to relieve the officer of the deck (OOD) if in his judgment the OOD is endangering the ship from a navigation standpoint” (Stavridis & Girrier, 2007). The logic behind such a rule is that the navigator is oftentimes a highly seasoned officer with more training and experience specifically in ship driving than most of the other watch standers on the bridge team. In accordance with the Navy’s Navigation Department Organization and Regulations Manual (NAVDORM), the navigation evaluator is primarily responsible for using all gathered electronic and visual data to determine the ship’s position and make recommendations for navigation (COMNAVSURFPAC, COMNAVAIRPAC, COMNAVAIRLANT, & COMNAVSURFLANT, 2013).

Even before the ship begins moving, the navigation evaluator has a medley of duties to perform on the bridge. Once a destination is chosen, be it a port or open sea, the navigation team must prepare the electronic (or paper) charts. This process involves updating the chart for recent changes, laying down tracks that are both safe and follow predetermined shipping lanes, and highlighting predominant landmarks that can be used as visual bearings. The NAVDORM requires that a navigation brief be performed no more than 24 hours before entering restricted waters (COMNAVSURFPAC et al., 2013). This brief has many requirements, but the primary purpose is “to provide a plan for safe and prudent passage, including piloting in restricted waters” (COMNAVSURFPAC et al., 2013). Beyond presentation of the voyage plan, the briefing also covers the expected weather, traffic conditions, engineering plant status, and emergency procedures for the operation. Oftentimes, the navigator will work with the conning officer well before the transit to ensure he understands the ship’s entire track.

When the transit begins, the navigation evaluator moves to the plotting table, a desk where paper or electronic charts are displayed, and begins his tasking. At this point, he must ensure fixes are being taken at the correct intervals, and that reports are being made properly. Fixes, both paper and electronic, are recorded positions of where the ship is at a specific point in time. This can be calculated by GPS, visual bearings, or even radar. Reporting is the process in which the navigation evaluator vocally indicates information to the entire bridge team. This is done in a loud and clear manner so that each person on the bridge hears the report.

Because today’s Navy has transitioned primarily to electronic navigation, relying strictly on GPS, the requirements of the navigation evaluator have changed drastically. Since the transition is not complete for every ship yet, the old methods of reporting are still be used by a few ships in the U.S. Navy. In order to qualify to solely use electronic charts, ships must receive full ECDIS-N certification. This process involves equipment installation, crew training, and system validation. For a fully qualified vessel, there are no structured reporting requirements for the navigation evaluator with the exception of emergencies or casualties. Typically, the navigation evaluator will let the conn (conning officer) know if the ship is getting too far off the track, when to turn, and if the conn has

ordered a course that is heading toward dangerous waters. Additionally, the navigation evaluator will offer course recommendation to regain track or compensate for set and drift. The reason for the less stringent requirements for ECDIS-N ships is because, on most vessels, there is a duplicate navigation display system in the middle of the bridge. This is typically where the conning officer will stand, and therefore he can look down at any time to see the same data that the navigation evaluator is looking at.

The reporting requirements for ECDIS-N ships are fairly open and situationally dependent; however, the same cannot be said for those ships not qualified for ECDIS-N navigation. Instead, the navigation evaluators on these ships must make constant reports at regular intervals during the entire restricted water transit. Time between reports is determined by the ship's distance from shoal water. In transiting restricted waters, such as the scenario used in the study, the navigation evaluator would make reports every three minutes. During the time between reports, the navigation team must take a fix, plot it on a paper chart, compare it with the onboard electronic navigation system, and make the verbal report. This report is highly structured, requiring that the following items be included (COMNAVSURFPAC et al., 2013):

- Fix Time
- Fix Quality
- Fix Method
- Fix Position
- Recommendations
- Supplemental Info (nearest hazard/aid to navigation, fathometer reading, distance and time till turn, next course, set and drift)

After every report, the conning officer and OOD are required to acknowledge their receipt and understanding of the information. Additionally, each time the conning officer orders a course change, the navigation evaluator must determine if the course is safe for navigation and report this information.

As the report for ships not certified to rely upon ECDIS-N is made at a regular interval and always contains the same amount of information, it provides a better testing parameter. The fact that there still remain ships that are not qualified for ECDIS-N made using this form of report acceptable for our testing purposes.

In conclusion, the navigation evaluator is a key member of the bridge team. Even with the minimal reporting requirements of today's Navy, conning officers still rely heavily on the reports and recommendation of the navigation evaluators. Given their years of shipboard experience and specialized training, navigation evaluators are expected to be able to deliver safe and accurate guidance to the less practiced conning officers.

C. RESPONSIBILITIES OF A CONNING OFFICER

Conning is the act of controlling the physical mechanisms that drive the ship (Stavridis & Girrier, 2007). The helmsman is an intermediate buffer to this process, but the conning officer makes the tactical level decisions that enable the ship to navigate safely. Primarily through multiple opportunities of hands-on training, conning officers develop the skill of taking numerous visual and aural inputs from various sources and making quick decisions that keep the ship safe. Visual inputs include: tracking the relative motion of the ship against known local landmarks, looking at the water for signs of active currents, and monitoring the digital navigation equipment on the bridge such as the Voyage Management System (VMS). Aural inputs include: listening for sound signals from approaching vessels, monitoring bridge-to-bridge radio to understand what another ship is doing, and paying attention to the navigator's recommendations. These examples only encompass a fraction of the total number of elements the conning officer needs to be aware of. In general, conning takes a significant amount of focus and a goodly amount of practice.

Conning is a very situationally dependent task. Depending on the class and mission set for the ship, a conning officer may be required to execute an underway replenishment in the morning and then drive through a minefield that same afternoon; a multitude of operations represent a reality of this position. The goal of this study was not

to test an AR display for every possible operation a conning officer can be involved in. Instead, this study focused on one scenario that takes place every time a ship gets underway from port. An outbound restricted water transit, as outlined in Chapter II, is a common task that every experienced conning officer must be familiar with. Therefore, the rest of this section will cover the basic tasks and steps that a conning officer would be expected to perform in the given situation.

Before a conning officer ever assumes the watch, he is required to fully understand the transit plan. The plan built by the navigation department is a collection of tracks and waypoints overlaid on a paper or digital chart that dictates how the ship will proceed out to sea. Each track includes: courses and distances for each leg, transit speed, turning points, and local navigation aids. Having a clear understanding of the entire plan allows the conning officer to focus on dynamic events that may affect the transit. These dynamic events include: set and drift, merchant traffic, adverse weather (i.e., fog), and engineering causalities. After the conning officer has familiarized himself with the transit plan, the ship conducts a navigation brief that details all watch responsibilities for the operation. At this point, the conning officer is responsible for presenting the transit plan to all parties involved in the evolution. This entire formal process is dictated by the NAVDORM, and is required before any restricted water transit (COMNAVSURFPAC et al., 2013).

The conning officer is responsible for issuing commands to get the ship away from the pier and into the channel to commence the transit. While issuing commands to the helmsman, the conning officer uses standard verbiage so that there is no misunderstanding of what was said or expected. Once away from the pier and on a track, the conning officer will order minor course corrections to compensate for set and drift or to avoid minor hazards such as fishing buoys. As the next course approaches, the conning officer will check their bridge wings to ensure that a turn will not cause the ship to run into another vessel that may be overtaking. When appropriate, the conning officer will order the helm to come to the next course and watch the rudder indicator for evidence that the helmsman is properly executing the order. Watching the heading change on the ship's gyrocompass and observing the surrounding land change perspective also gives the

conning officer an indication that the ship is turning and how fast it is doing so. This process continues until the ship reaches the end of the navigator's track and the bridge team begins following normal at-sea procedures.

A conning officer demonstrates his skills by being able to manipulate the ship's engines and rudder to keep the ship in safe water. The reason why the term "safe water" is used in lieu of driving close to track is because closely following the planned track may not be possible due to a myriad of reasons, such as other vessel traffic, significant currents, or even dynamic security events. Barring unforeseen occurrences, driving close to the predefined track provides the safest method of transit. In order to stay close to the track, a conning officer must take in all visual and audio cues available and output correctly formatted orders that either regain or maintain the base course. This is done by looking at how far off the track the ship is, calculating a proper course to regain that track, and then compensating for set and drift. Once all the calculations are complete, the conning officer must translate what they want to do into the proper verbiage to give clear orders to the helmsman. Being able to quickly and accurately compute these calculations instantaneously is the hallmark of a skilled conning officer.

Conning officers must also be able to cope with emergency situations and to keep the ship in safe water during restricted transits. These emergency situations can include a man overboard, engineering casualties, and near collision situations. However, since the study did not include any of these situations, they were not covered in this section.

D. SUMMARY

This chapter has focused on responsibilities of three key members of the bridge team during a routine channel transit. There are several other operators on the bridge during a restricted water transit, but to minimally represent the ship driving aspects of the operation these three positions are fundamental. The research study focused on measuring the performance of the conning officer who was asked to perform in a team operation. It was therefore important to properly replicate the actions and responses of the other two positions so that test subjects would execute their tasks most effectively and in the same manner in which they would perform on a real ship.

IV. EXPERIMENTAL TESTBED ENVIRONMENT

This chapter details the technical applications and processes used to design, program, and simulate the testbed environment. Each decision made during the design phase had a significant impact on how final testing would be conducted. Additionally, the usefulness and accuracy of the collected data was discussed in the context of realism and precision of the simulation. Overall, the chapter details the challenges we came across, and a set of solutions that were developed and tested in our effort to create the most optimal version of a dynamic real-time ship driving simulation that would support user study.

The initial discussions and considerations focusing on the prototyping and testing of an augmented display solution for conning led to an inevitable conclusion. Given our need for repeatability, safety, and the ability to modify the software and use it in conditions characteristic for AR, it would be a nearly impossible task to conduct experimentation onboard an actual ship busy conducting regular operations. Instead of a true AR setup, a decision was made to virtualize the entire experimental environment. This decision coincided with a simultaneous emergence of a cheap VR headset in the commercial market and thus led to the decision to develop and operate completely in VR using a head-mounted display solution.

A. HARDWARE

1. Immersive Display Solution

We decided to use the Oculus Rift HMD as our immersive display for this experiment. Historically, the price of a good VR headset had been quite prohibitive for most applications. Additionally, the headsets themselves were bulky, heavy, and difficult to program for, limiting their usefulness as a research platform. In contrast, the Oculus Rift took advantage of the recent development of fast and cheap mobile displays. The company declared its vision to be a distribution of “immersive virtual reality technology that’s wearable and affordable” (“About Oculus,” 2015). By March 2014, it has commercially released two development kits, each kit consisting of a head-mounted

display, appropriate cabling, and software integration packages. The first development kit (DK1) was released in late 2013 while the second development kit (DK2) was released in March 2014 (“Oculus VR,” n.d.). A comparison of the technical specifications of each is shown in Table 1.

PARAMETER:	DK1	DK2
Resolution (per eye)	600 x 800	960 x 1080
Display Technology	LCD	OLED
Display Refresh Rate	60 Hz	60, 72, 75Hz
Persistence	~ 3ms	2 ms, 3 ms, full
Visual FOV	110°	100°
Tracking DOF	3	6
Weight	.83 lbs	.97 lbs

Table 1. HMD Comparison (after <http://riftinfo.com/oculus-rift-specs-dk1-vs-dk2-comparison>, <http://in2gpu.com/2014/08/10/oculus-rift-dk1-vs-dk2/>, and <https://www.oculus.com/dk2/>)

(1) DK1

The first hardware released by Oculus, the DK1, was a low resolution headset with more focus being put on the tracking and software development than the graphics. The resolution of display surface was 640x800 per eye with a 106 degree field of view (FOV) (Oculus Rift development kit, n.d.). The headset was light (380 grams) and reasonably comfortable allowing for extended use. Priced at \$300.00 USD, the company sold over 60,000 units (Buley, 2014). In preparation for our study, we thoroughly tested the headset and came away with several positive opinions about it. Firstly, the unit was easy to set up and develop with. Because the device acted as an additional monitor that relied on an “extended desktop” metaphor, setting it up required only plugging in one High-Definition Multimedia Interface and one Universal Serial Bus cord. The device was essentially plug-and-play as the drivers utilized by the software were all loaded up on the startup. This eliminated the need for an external application dedicated to monitoring the motion tracking sensors to be running on the host computer. Secondly, the motion

tracking was visually impressive, supporting 3 degrees of freedom and with latency of around 2 ms (“Oculus Rift Development Kit,” n.d.). For such a low price point, the highly precise motion tracking of the unit allowed for better sense of presence, had a potential to cause less cybersickness, and offered a better overall user (operator) experience. Our biggest complaint about this hardware was the very low resolution of its display. With a resolution of only 640x800, any scene rendered in the headset appeared to have an overlay of a visible pixel grid. As our simulation would require not only a detailed ship’s bridge but many augmented HUD elements that needed to be easily read, we determined that this headset would be unsuitable for further testing and operation.

(2) DK2

The second hardware release by Oculus came with several improvements not only in resolution of its display, but also in motion tracking. The DK2 has a resolution of 960x1080 per eye and although there still remains some pixelation, the images displayed in the center portion of the display are much clearer. This model came with an upgraded motion head tracking system utilizing an infrared camera system. This resulted in providing 6 DOF of head motion tracking with latency comparable to its predecessor. As a user navigates through a VE, this type of tracking allows for actions like leaning in, crouching, and strafing (moving sideways). Due to a significant change in the hardware design, the DK2 requires a software program installation on all devices utilizing the headset. This software includes a configuration utility and background processes not seen in the first development kit. Due to this design difference, we needed to introduce significant changes at the software level when developing the experimental environment (details of these changes are provided in the following sections). The most significant change was the inability to continue using the “extended desktop” mode on one computer to render both the operator view and control view. Instead, a networked solution of applications on two computers was developed. Our efforts were also directed toward limiting the effects of cybersickness on the test subjects and running both the training and ship driving simulations at approximately 75 frames per second (FPS).

(3) Unity Integration

With the new emergence of consumer-grade VR hardware being brought to the market, tools to create rich interactive VEs are also needed. Recent strides in the indie video game industry have led to the development of a design platform called Unity. Developed in 2006, the Unity game engine “was created with the vision to democratize game development and level the playing field for developers across the globe” (Unity, n.d.). This game engine supports simple scene creation, animation capabilities, real-time physics rendering, and highly customizable scripting. Combined with the free distribution of nearly all these tools, this provided a perfect development environment for the study.

Oculus released both DK1 and DK2 with accompanying software development kits that utilized Unity prefabricated packages. This allowed for VR integration into any first-person VE with little more than one click to unpack the provided packages. While the AR integration that would be utilized in the study would require significant modification of these provided scripts, the basic plug and play modularity of the provided software development kit (SDK) saved a lot of time during development.

2. Computer Systems

The final version of the software used a networked solution in which the real-time image generation (rendering) occurred on one computer while the ship movement and behavior (its responses to VE and its dynamic conditions) was controlled with a secondary computer.

We required a computer with significant processing power to render the 3D scene in real-time with high display frame rate and to support responsive head tracking. The following system configuration was used in the primary computer:

- **Processor:** Intel Core i7 4930k CPU @ 3.40Ghz (6 core)
- **Memory:** 16 GB 1800hz Ram
- **Graphics Card:** NVIDIA GeForce GTX 690
- **Operating System:** Windows 7

The secondary computer was not used to do any intensive graphical processing and thus any current generation computer can be used. In case of this study, we used Apple's Mac mini with following configuration:

- **Processor:** Intel Core i5 2.50Ghz (dual core)
- **Memory:** 16 GB 1600MHz Ram
- **Graphics Card:** Onboard Intel HD Graphics 4000
- **Operating System:** OS X 10.10.1

The physical setup and connection of the computers is outlined in Figure 2.

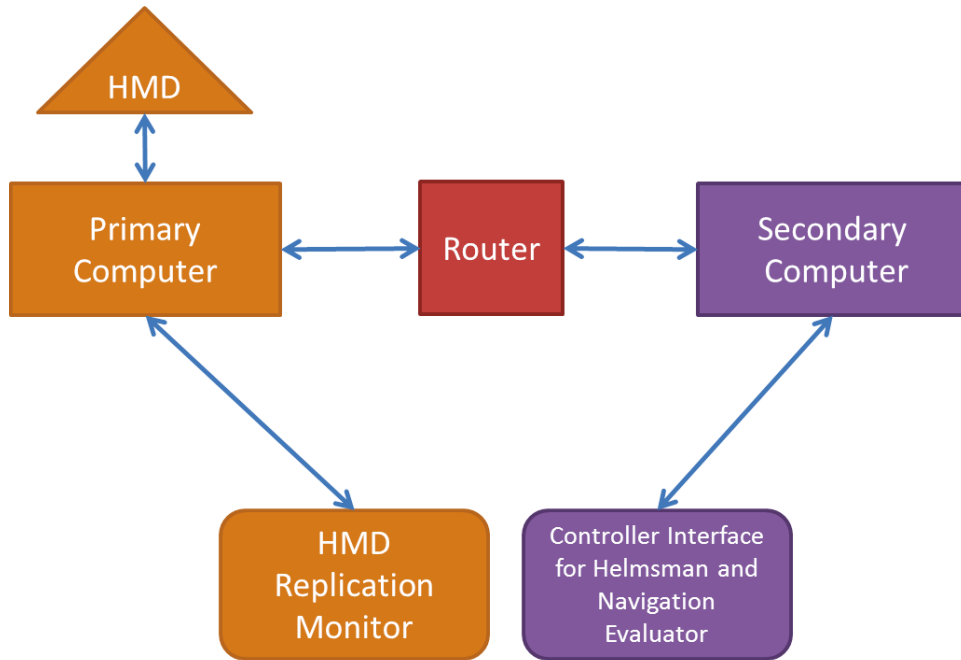


Figure 2. Device Connection Map

3. Networking Solution

The final solution of the experimental environment required that both computers be connected in a stand-alone network. Knowing that we would be unable to use an existing network, the software was developed to use the following networking hardware.

- **Router:** CISCO Linksys E1200

- **Cabling:** 2 * CAT5e cables

4. **Audio System**

While the environmental audio was not a critical factor in the study, a decision was made to play the sounds of the ocean during the experimental sessions to reproduce as realistic a sound stage for the experimental session as possible. The elements of the audio-setup consisted of the following segments:

- **Speaker:** Photive Hydra Bluetooth Speaker
- **Playback Device:** Mac Mini
- **Recording:** A recording of the ocean at low tide was used (Roberts, 2009). The audio clip is 10 minutes and 11 seconds long and features sounds of the ocean waves breaking against a shoreline and seagull calls. The recording was played on repeat for the duration of each experimental session.

B. **SOFTWARE**

1. **Initial Design Decisions**

While we decided early on that we would use VR technology in our user study, the actual configuration of the experimental environment went through many iterations and design changes. We started with major system requirements and made our initial selection of the platform. Firstly, we needed a custom-made software application in which we could utilize the Oculus Rift or a similarly designed HMD. Secondly, we needed complete access to the application's source code such that we could add the augmented layer for the HMD. Lastly, the 3D environment had to be realistic enough such that test subjects' sense of presence would be as high as possible with no major distractions to cause breaks in presence. We wanted them to feel as if they were on the deck of the ship and thus instantly begin conning without the need for extended acclimation to the simulated environment. It was necessary to ensure that the experience of driving the virtual ship was close enough to the way it is done in a real (operational) environment such that adding the experimental HUD would be the only significant variable to the comparable real-world scenario.

The U.S. Navy already uses VR technology in its shipboard trainers. Located in Newport, Rhode Island, “the Conning Officer Virtual Environment (COVE) stations provide state of the art navigation and shiphandling training for all of our [U.S. Navy] surface officers. These trainers can emulate all of the U.S. Navy’s homeports in addition to almost every routine port of call around the world” (COVE, 2014, p. 1). The COVE system also encapsulates a validated physics engine for all primary classes of ships. These types of characteristics drew our initial intention toward the COVE system and made us consider using this system and its training program in our own testable HUD. However, we very quickly determined that a proprietary nature of the entire system would prohibit making changes to the source code that needed to be introduced in support of our study.

Our secondary option was to go with the software that was already available within the Modeling, Virtual Environments and Simulation (MOVES) Institute. In 2011, while attending NPS, Lieutenant Commander De Moraes created an entire ship driving trainer utilizing the open source Delta3D engine (2011). This training simulation was designed to address “the need for a navigation and shiphandling game-based training system at naval academies” (de Moraes, 2011, p. i). After testing out the software and taking a look at the source code, we determined that integration of the Oculus Rift hardware with this code would be a non-trivial task.

As discussed in the Chapter III, the Oculus Rift was designed to be supported by contemporary game engines such as Unity or Unreal Engine. At the time, there were no integration packages available for the Delta3D engine. We determined that, given the alternatives, the most effective way to create a usable experimental environment for the study would be to build a new custom application in a Unity environment. Having made this determination, we began the development of a VR ship driving simulation in March of 2014.

2. Simulation Development

a. Unity

Unity is modular game development software suite that allows users to take nearly any format of 3D model and create rich VEs. With an active community of over 2,000,000 registered developers, there is a large number of tutorials, example code, and forums available online, making it an easy platform to work with. We used a combination of publicly available 3D models as well as 3D models already created by the Visual Simulation and Game-Based Technology group at NPS for objects in the NAVHUD simulation. The scripts utilized in the study were all written in C# programming language. Most of the issues detailed in this chapter were tested and created in isolation, and then subsequently integrated into the main simulation.

b. Initial Design

A need for two independent views, an operator view and a controller (experimenter) view, became evident soon after the coding for the simulation began. The operator view represented the first-person perspective from the ship's bridge displayed inside the Oculus Rift. This showed what the conning officer would see from the bridge. Additionally, the controller (experimenter) view would be a two-dimensional graphical user interface (GUI) featuring a series of ship driving controls and raw sensor data outputs (readings). These panels would not only allow the "helmsman" to drive the ship, but they would also be used by the "navigation evaluator" to construct verbal reports for the conning officer.

In the first stage, we used the DK1 to mirror a single monitor for a conning officer (the subject in the study). A dual monitor design (i.e., extended desktop metaphor) supported both the subject (conning officer) and two experimenters (helmsman and navigation officer). This design presented the visual output generated by the simulation over two monitors; the first being dedicated to the operator's view and the second being dedicated to the controller view. The monitor dedicated to the operator was duplicated on the Oculus Rift—this way both the operator (subject/conning officer) and the controllers (experimenters/helmsman and navigation officer) were able to see the same visuals. The

initial stage of code development that lasted several months used this method - all needed data were properly displayed within one running executable application. While simplistic in its overall structure this design satisfied the basic needs of the study. Although we realized that the low resolution of the DK1 made it unusable in the study, we planned to transition to the DK2 after its scheduled release date in July of 2014 (Oculus Team, 2014). Being that both units were produced by the same company and bundled with similar Unity integration packages, we assumed that any software developed using DK1 concepts would be forward compatible to the DK2.

After its arrival in late July, the DK2 was thoroughly tested and significant differences in the hardware implementation were discovered. Whereas the DK1 primarily acted as an additional monitor on extended desktop, the DK2 was much more sophisticated and even required a software executable to be running in the background to manage the device. While this was beneficial to many programs that would utilize the Oculus Rift hardware, it proved to be detrimental to the initial system architecture that we had created for the study. The benefit that this new software provides is that it no longer requires a screen to be mirrored for the hardware to work but instead; the Oculus applications are ran as background tasks and still render perfectly fine in the HMD. Given the impossibility of running the shipboard VR environment that had been developed thus far within the DK2, (since there was no support for extended desktop in configuration needed for our study) we determined that a networked solution was the only feasible option.

c. Networked Solution

Moving to the networked solution required by the DK2 was a difficult task. After several methods of splitting up the application and testing it (special attention was paid to operator's visual experiences and usability during the actual sessions), we determined that the best course of action was to have the operator's view of the simulation acting as a host and the controller's view of the ship to be a client application. The primary reason for this specific host-client configuration was that the Unity networking utilities caused slight delays in client applications. It was critical that the scenes rendered in the HMD

and related visual flow be as smooth as possible to minimize if not completely diminish the symptoms of cybersickness; this was achieved by using the application responsible for the operator view to be the host application.

In the final design of the simulation, both the host and client start loading up an identical scene but from different perspectives. This scene represents a ship that is stationary in the water placed at the start of the channel. The host application depicts the first-person view from inside the bridge whereas the client application presents a third-person perspective following the ship from a set distance above and behind the ship. The host application integrates the AR graphics and the client is where the ship controls and navigation reports were placed for the benefit of the controller (experimenter).

The process of adding more 3D objects, scripts, and physics to the simulation increased the lag in the HMD. The overarching goal for the study was to design a system that looked and felt real enough to complete the task of conning a ship out of the channel while simultaneously not causing the user discomfort due to cybersickness. It was therefore critical that the execution of the host application contained as little overhead as possible. In order to do this, we had the host and client computer run the same simulation while the client sent small remote procedure calls (RPC) to itself and the host. These RPCs included information about the engine and rudder orders, shifts of the navigation waypoints, and bridge movement commands.

The last segment we developed to help control this networked solution was a GUI that was used on client computer to initiate the connection between the two devices. This GUI comprised of a textbox for subject identifier, selectors for the experimental condition to be used in a given session, and a textbox for the local Internet Protocol (IP) address. Once submitted, the two programs would create a connection allowing the RPCs to be passed back and forth. As a means of making things simpler, the IP address box was populated with the local IP address of the client application. Because both devices would always be on the same router, only the last three digits needed to be changed to specify the host.

d. 3D Ship Model

One of the design priorities was selecting highly detailed 3D model of a U.S. Navy warship. The ideal vessel for testing was a cruiser/destroyer sized warship; our guidance in this decision was the assumption that more surface warfare officers, our potential subjects in user study, would have the knowledge and skills to drive this size of ship than our other options. The best model available to us was a model of a Littoral Combat Ship (LCS) in the MOVES Institute repository of 3D models. The most significant issue with the model however was a lack of geometry description for internal rooms. That meant that we had to design geometry of the bridge and insert it into the 3D model of the ship. The image in Figure 3 shows the outer hull of the ship and the image in Figure 4 shows the internal design of the bridge; the entire model of the ship used 60,000 polygons. Photos of the real ship and bridge were used as a reference to ensure that the design replicated a “look and a feel” of the real-world LCS bridge as much as possible.



Figure 3. LCS Model (60,000 Polygons)



Figure 4. LCS Bridge

e. Environment

The next step toward creating a highly realistic scene was the acquisition of a 3D model that described the terrain and water environment, both needed to simulate the ship transit. The initial attempts focused on using a scaled model of San Diego Bay; we imported the terrain height data and overlaid Google Map aerial imagery. This created a very realistic scene that depicted a locale known to naval officers. As the design of study progressed, we recognized that in order to get usable data we would need to make certain aspects of the transit artificial. The San Diego transit had significantly long tracks, and skilled conning officers would have no difficulty gaining and maintaining track over those distances; this locale would not challenge their conning skills and thus not provide us with the best basis to test our research hypothesis. Therefore, we decided that a far better solution would be to have a series of shorter legs with distributed winds and currents in them that would force conning officers to take significant action to conduct their basic task - to drive the center of the track during each leg of the transit.

The creation of an artificial environment (3D model of the terrain and water) brought about several advantages. Firstly, it allowed for a consistency of length for each

leg. We ended up choosing 1,500 yards for each transit leg. With 1,500 yards per leg, we were able set the transit speed at 15 knots (a reasonable speed for an outbound transit) and have the turns between the adjoining legs happen every three minutes. In the study, we needed each participant to drive the same transit three times (once in each experimental condition). Additionally, it was necessary to optimize the total time of each session so that the entire experience for one subject did not last too long. At three minutes per leg and a desired total time of 15 minutes per condition, we ended up with five legs per user per session (condition). This allowed each run to produce statistically significant data. The second reason for a consistent leg length was the ability to guarantee that each leg would provide ample time for three full navigation reports, the significance of which will be covered in greater detail in Chapter V. Finally, the consistent leg length allowed the conning officers to focus on their task of staying on track while knowing that turns would occur at regular intervals. The “three minute rule” is a commonly used tool for those who drive ships as a part of their regular professional duties. Stated simply, in three minutes a ship will travel its current speed in knots multiplied by 100 yards. In this case, with a constant speed of approximately 15 knots, the conning officer would know that 1,000 yards until turn would have given them two more minutes to regain track, and so forth.

The scene developer tools in Unity software package were used to craft a fictitious channel that consisted of five legs of 1,500 yards each. The image in Figure 5 shows six legs, the first being a starting leg that required no commands from the conning officer. This initial leg also gave the ship opportunity to come to speed before the conning officer needed to take action. We also included several lifelike 3D models of other stationary vessels as well as buildings, all aimed at increasing a sense of presence of the subjects in our study. We acquired all of these models either through the MOVES Institute or through free online model sharing websites (e.g., www.turbosquid.com and www.tf3dm.com). The image in Figure 6 presents a more realistic depiction of what the conning officers would expect to see during their transit.



Figure 5. Map of Isla Verde with Track Details

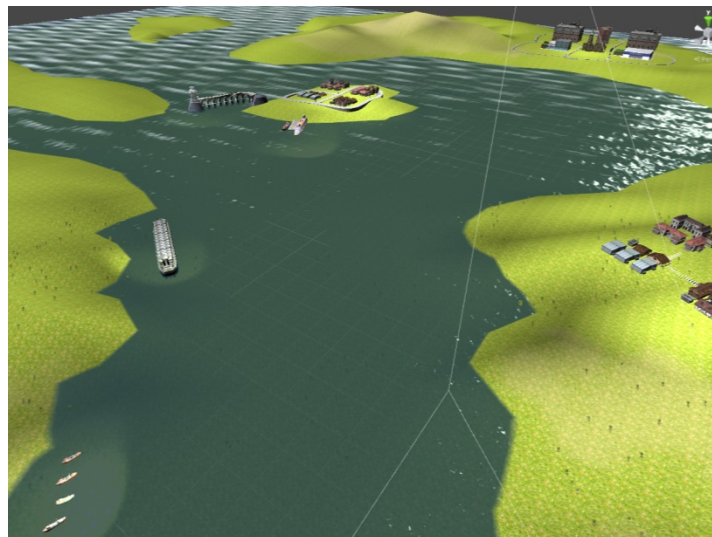


Figure 6. Isla Verde with 3D Models

f. Ship Physics

(1) Acquisition

Besides finding an adequate ship model, the physics engine for moving the ship through the environment was the most important requirement to accomplish while recreating the elements of environment that conning officers would respond to. If the ship handled significantly different from the expectations of the subjects (conning officers) then the learning curve for each session would render any collected data useless. Modeling the ocean physics systems is a non-trivial endeavor and requires a significant amount of expertise; therefore considerable efforts were invested to find and incorporate existing high-quality maritime physics model into our application. During an exploratory visit to the labs of BlueShark at the Institute for Creative Technologies at the University of Southern California, we discovered that they had already designed such a system for their AR demonstration model. Blueshark is a team of researchers and engineers sponsored by the Office of Naval Research (“E2C2 Team,” 2015). They specialize in the research and development of augmented and mixed reality systems tailored for military application. The system that we wished to partially emulate was a ship driving experience that integrated a full immersion HMD with infrared tracking gloves. While not fully based on genuine physics, the system paralleled the real-world motions of the ship quite accurately. The BlueShark team was willing to share their code that governed the physics of the ship and that became the baseline of ship movement through the water.

(2) Integration

The shared code represented an engine with function calls, and thus it was necessary to build a custom driving interface that would allow the operator (helmsman) to easily control the engines and rudder of the ship. The initial creation of the driving controls was simple; however, significant changes had to be added to support the networked solution of the system. We decided that, using RPC functions, the client application would send orders to both itself and the host simultaneously. These orders were either propulsion values or rudder angles (details on the final design of the driving interface can be found in the Controller HUD section of this chapter.)

The system integration involved more than simply adjusting the inputs to the physics engine. Because the Unity game engine allows the models to be scaled arbitrarily and the physics engine we were using came with no guarantee of being validated, there was no immediate way to tell if our ship was really traveling at its reported speed or not. To validate that they performed correctly, we performed many tests with 3D models and integrated ship behavior (physics) to check the scale, speed, and turning radius values of the vessel. Using this approach, we were able to verify the data we need to accurately report on parameters such as speed over ground (SOG), distance off track, distance to next turn, and others.

(3) Optimization

The trial runs of conning a demonstration course helped us determine that, without the inclusion of external forces which would additionally influence the motion of the ship, the task in our study would be too easy for skilled conning officers. The measurement we were interested to collect and record was distance off the track throughout the transit. In a situation with perfect environmental conditions the offset from the main track would be minimal in each session, providing us with no significant results and no basis to test our research hypothesis. To increase the difficulty of the transit, set and drift forces were added to the simulation.

Set and drift are forces enacted upon vessels from both winds and sea (ocean) currents. Set refers to the direction to which the ship is being pushed. Drift is the speed at which these forces are pushing the vessel. Since no such system was built into the physics engine we had adopted, the appropriate model of those forces needed to be added to the overall engine. Once this model was completed, the controls to physically adjust the forces of set and drift were integrated into the waypoint system. The waypoint system - covered further on in the chapter—is the primary scripting agent for our experiment. This system dictates the course track, external forces (set and drift), and records performance data.

(4) Course Over Ground

During the final stages of testing, we paid special attention to the accuracy of the reporting mechanism for the ship's course over ground (COG). COG is an important report to understand. Ships do not always move in the direction they are headed. The influences of wind and current on the ship act as independent vectors that, when added together with the ship's own propulsion vector, can lead to a direction of motion that is different than the direction of the ship's heading. When this effect is significant, and the ship must point its bow in a different direction than the course it wants to make in the water, this is called "crabbing" (Figure 7). From the perspective of a conning officer, when he orders the helmsman to steer a certain course and the ship's COG differs significantly from the ordered course, that is a clear indication of how set and drift are affecting the vessel. Alternatively, if the conning officer knows what the set and drift are, he can anticipate their effects and order a course that compensates for these elements allowing the ship to maintain track. When the addition of the set and drift mechanics first occurred, the effects it would have on the COG report were overlooked. The final version of the reporting function took into account this phenomenon.

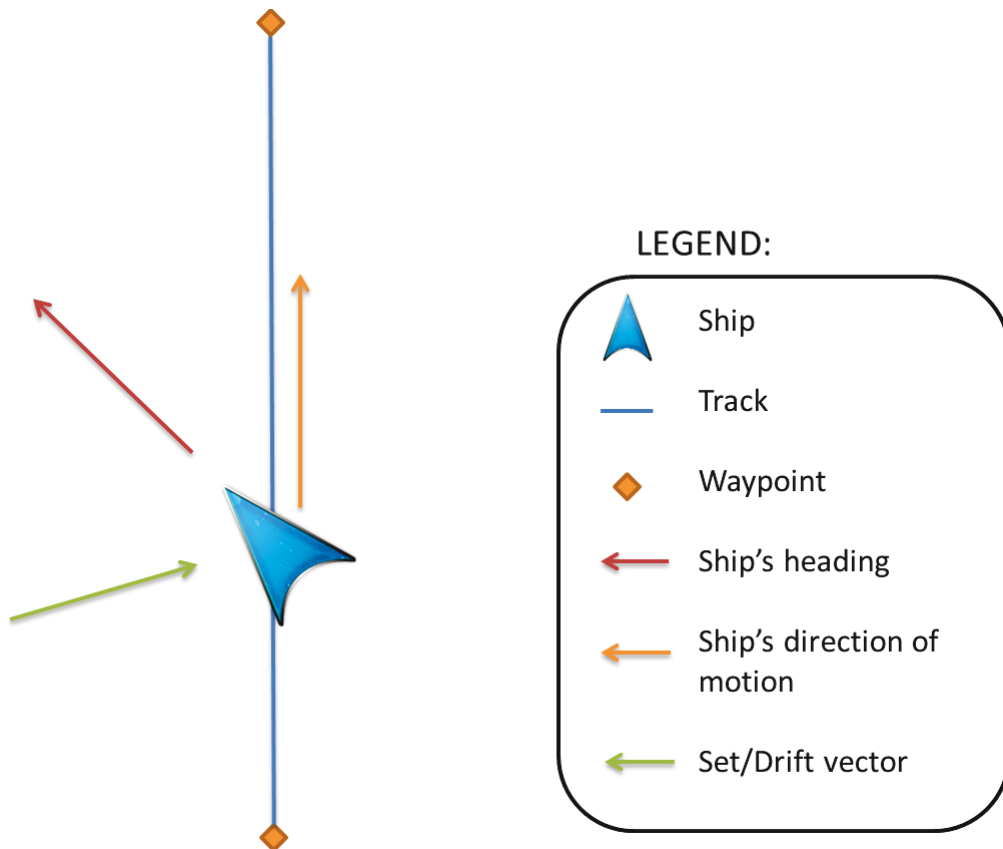


Figure 7. Depiction of a Ship That Is Crabbing

g. First-Person Movement

One of the goals for this project was to utilize emerging VR hardware systems capable of supporting user interactions that had never been employed in the realm of ship driving simulations before. A task that had never been tackled so far was to allow users to actually walk, i.e., freely navigate around the bridge. The closest simulation that has allowed for this was the Navy's Full Mission Bridge (FMB) Simulator ("FMB," 2014). This system is a physical mock-up of the bridge which has large screens placed in a semi-circle around it. The trainees can move about freely about the bridge mock-up. A clear advantage of this system is that it provides a highly realistic multiuser experience which trains many roles simultaneously. The most significant disadvantage of this system is the extremely high cost to build and run such a trainer. Excluding the FMB, most other simulators place the conning officer on the bridge and allow him to move to the bridge wings via a warping movement that can be best explained as a teleporting capability. The

systems usually incorporate a series of viewpoints, inside and outside the ship, to which the conning officer can ask to change his current view. One of the goals of the NAVHUD project was to build a system in which the users had a full control of their movement on the bridge.

We started with a goal of full human locomotion. The Virtuix Omni, in many aspects, mimics the effort taken by the Oculus team in their attempts to bring a commercial VR to the masses of potential users (Figure 8). The Omni brings the capabilities of a multidirectional treadmill by keeping a user in place while he moves around (locomotes) in the space. The user is strapped around his waist to the support ring, and he locomotes inside a concave, spherical platform, while the curvature of the surface as well as the weight of the user brings him “back” toward the center of the platform, i.e., the place where he started (tracking sensors are attached to the user’s shoes.) Users can put on a HMD and see their physical movements replicated in the simulation. This product was initially scheduled for its release in August of 2014, and was seen as a viable way of allowing subjects to physically control their own movements while navigating on 3D representation of the bridge. Scheduling delays resulted in the product not being released in time for testing, and therefore a different navigation method needed to be adopted and developed for the study.

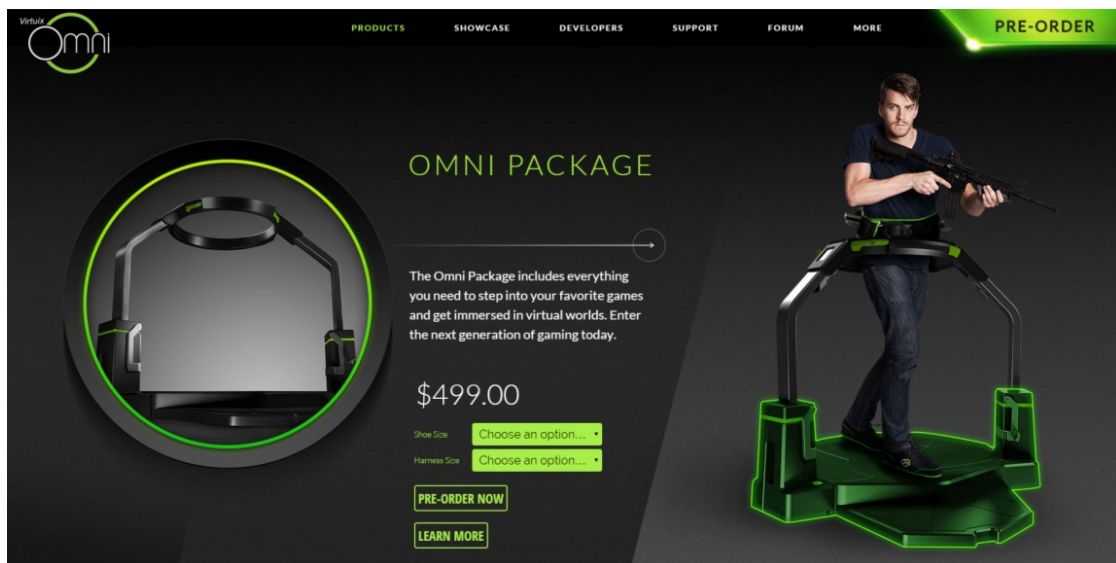


Figure 8. OMNI Hardware (photo used with permission from Virtuix, n.d.)

A special amount of attention was invested in devising a correct transformation mechanism for each object in the scene. Most specifically the movement for the conning officer on the bridge needed to account for the vessel's own movement. The challenge was allowing the character to move independently of the ship, while simultaneously applying the ship's own movement vectors to the character. With the help of the MOVES Visual Simulation and Game-Based Technology group, an adequate solution was devised. The key to the solution was to attach the character to the ship so that ship position updates would trickle down to the character. The second step was to write code into the LateUpdate() function so that these transformations would not collide with the ship's own transformations. This resulted in smooth movement of the character.

Since the acquisition of OMNI hardware did not materialize, a secondary option for character movement was sought. An initial suggestion was to use controllers such as an Xbox360 game controller to give subjects direct control over their movement i.e., navigation through the 3D scene. We decided this solution was inadequate as it would require additional training for subjects not familiar with game controllers. We also wanted to avoid an unneeded distraction in the basic task of ship driving.

Instead, we implemented a method often utilized in arcade first-person shooters called "rail shooters." This method uses several predefined viewpoints in any scene and moves the user automatically and smoothly between them. This particular solution was determined to be adequate based on our knowledge of domain space and the behaviors exhibited by the operators - conning officers would only be likely to place themselves in one of a few typical places on the bridge from which they usually observe the outside environment and conduct their tasks, and so there was less need to allow complete freedom of movement within the bridge. The positions in this study included the "centerline" (middle of the bridge) and the left/right bridge wings respectively. The final results allowed the conning officers to verbally ask the experimenter to move him to one of four possible positions on the bridge: (1) the left bridge wing, (2) the right bridge wing, (3) the left-center bridge, or (4) the right-center bridge. The reason for the separation of the centerline bridge positions is because our model is of a LCS class ship where the centerline is blocked by a support beam and electrical control equipment.

h. Water Rendering

Another important element of a realistic 3D shipboard environment is a very good simulation of water. Similar to our search for 3D models of ships and the surrounding environment, a tool to realistically render water was sought out early in the design of the simulation. Physical cues such as the direction and speed of the current, depth of the water, and overall sea state can be derived from the look of the water surface. These cues are essential inputs to the conning officer, who will in turn give commands that account for the additional forces acting on the ship. If the water that was rendered was perceived to be too unrealistic, we supposed it would have been a source of distraction for the test subjects. An initial investigation led to the choice of an engine called Triton Oceans by developer Sundog. While the software is a popular choice for use by military simulation companies, the primary reason for use was their excellent water rendering samples (Figure 9). The system not only renders realistic water, it also adds a simulation of ocean currents, buoyancy, and winds (the effects we judged as necessary in our simulation). The tools themselves are designed as packages that can be easily imported into the Unity game developer and we hoped that the final integration would be simple. After attempting to integrate the ocean packages into our simulation, a significant issue was discovered. The Oculus Rift uses two separate camera positions in the scene and then applies multiple effects during the rendering process. This process allows for the stereoscopic vision, i.e., it enables stereoscopic depth cue that gives the user an impression of being in a 3D environment. Due to the complex rendering techniques used, the final rendering of the Triton Ocean assets processing showed numerous artifacts. This issue was known by the team at Sundog Software and has since been fixed, but that did not occur in time for our testing (Dykes, 2014).



Figure 9. Triton Ocean Example (used with permission from Sundog Software, n.d.)

Several attempts were made to work with the team members of Sundog and BlueShark; however, no solution was found for correct functioning of the Triton Ocean water rendering in our application. Instead, we decided to use the built-in water rendering tools provided by Unity. The image in Figure 10 shows a water scene rendered by the professional version of Unity. While it is possible to apply physics and waves to this ocean package, scheduling timelines prevented the design team from manipulating the water to these extremes.

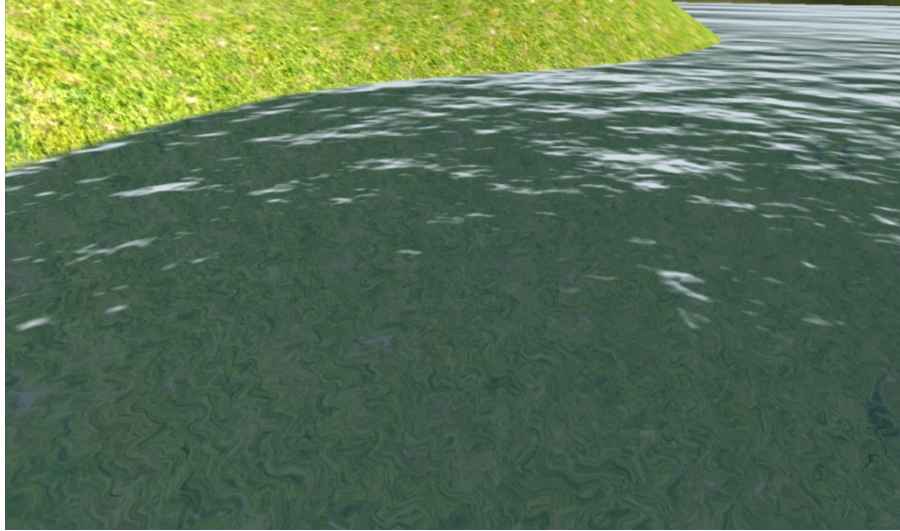


Figure 10. An Example of Unity Water Rendering Used in NAVHUD Study

i. Ship Waypoint System

The task of creating a ship waypoint system consisted of three main goals. Firstly, the waypoints had to be populated using a standard method that allows for predetermination of the distance and angle between them. Secondly, the ship had to be tracked along the paths between the waypoints. Lastly, there had to be a standardized method of calculating when to have the tracking system shift to the next leg correctly. The concepts of each of these goals were fairly simple; however, the actual coding of each element was non-trivial.

The waypoint system was designed to be the backbone of the entire data collection system. We created a track that forced the subjects to utilize all their conning officer skills while simultaneously providing good points of reference for data collection. The general concept was that the waypoints needed to be placed on the map in such a way that the tracks created between those waypoints were all standardized. Additionally, the waypoints needed to take into account the precise turn angles between them. The final solution incorporated manual calculations for the positions using vector mathematics, and then placing the waypoints in the scene accordingly. The angles and distances were used as parameters in a formula that used an origin point (3D Vector) as input and produced a series of coordinates for the waypoints. The final result was a highly precise course with

exact turn angles and distances. As shown in Figure 5, the final version of the course included five turns averaging 64 degrees with three turns to starboard and two turns to port. This was determined to be an adequate challenge to the participants while still being a realistic representation of an actual transit.

The second challenge was to build a tracking mechanism for the course. The calculation of how far along the track the ship had traveled was a simple vector subtraction problem, but more complex step was to calculate the data that indicated the distance away from the track. Using vector mathematics, we implemented a system that reported the exact distance left or right of track. An elegant coding solution for this method was found on Unity's own message boards, and it was deployed in our code (McDroid, 2011). The basic concept was to take the difference between the current location of the ship and the last waypoint hit. A cross product of the direction of the track and the result of that subtraction gives a new vector. This final vector's "y" component is the distance off the track (if it was negative it was right of track, if it was positive it was determined as left of track). The simulation recorded the distance off track once every 10 yards as the ship approached the next turn. To exclude erroneous data collected during the turns themselves, the system started reporting this data at 1,350 yards till the next turn (note: each leg was 1,500 yards long).

The final function of the waypoint system provided the capability to adequately judge when a turn was to be made. The initial design relied on placing a theoretical circle around the waypoints themselves and having the system shift waypoints when the ship entered the area of these circles. During testing this was discovered to be an inaccurate way of determining when to shift the waypoints. The problem was twofold; firstly, if the ship was significantly left or right of track then it would never enter the circle and thusly the next course would never be triggered. Secondly, the method of reporting distance to the next leg was calculated incorrectly. The initial calculation took the next waypoint location and subtracted the ship's own position. As ships that are left or right of track need to compensate for their turns using advance and transfer tables, the measurement of distance to waypoint is not nearly as useful as a measurement of distance from the next leg. This effect is highlighted in the image in Figure 11; the red line represents the initial

execution and the green line represents the correct method to measure distance to turn. To calculate the length of the green line, a ray from the ship's position was extended in the direction parallel to the current leg direction. The distance between the ship and the intersection of this line with the next leg is what was used in the final simulation.

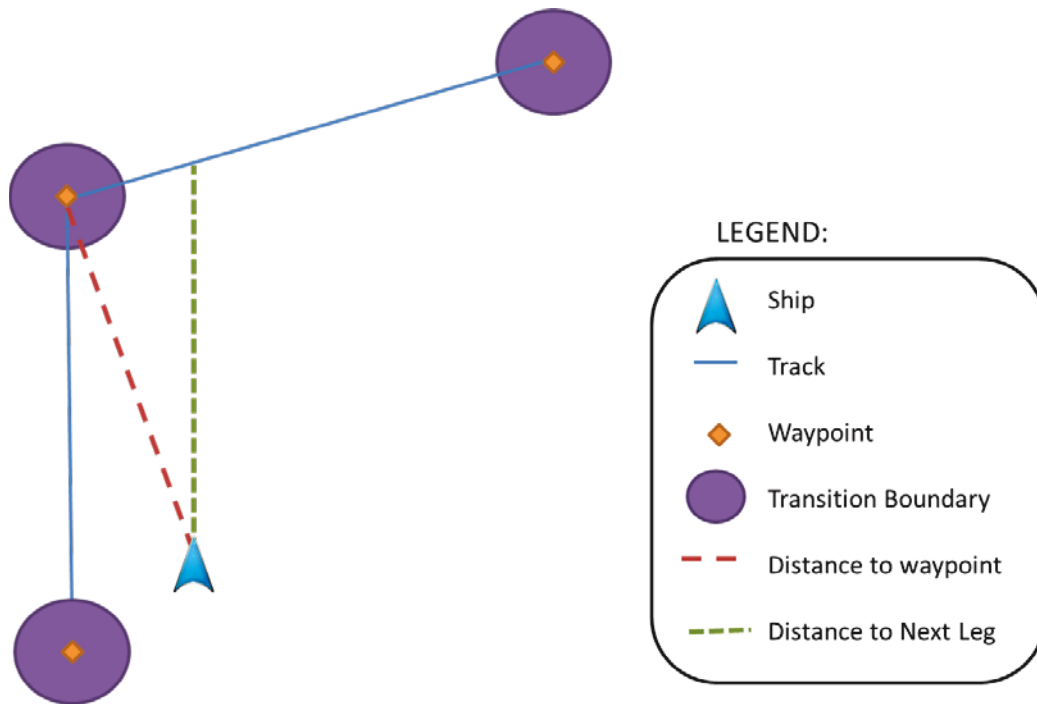


Figure 11. Turning Mechanism

In order to accurately determine when the ship should turn, we had to take advance and transfer into consideration. The image in Figure 12 presents advance and transfer. Ships do not turn instantly, thus calculations are used to precisely determine when the ship must begin a turn so that they end the turn in the center of the next leg's track. The variables taken into account are the ship's speed, the angle of turn, and the ship's handling characteristics. A number of tests were run to help us build accurate advance and transfer tables for the vessel used in our simulation. These tables were then applied to the recommended distance-to-turn value conveyed to the conning officers. This was done so that no matter how far off (left or right of) course they were at the end of a leg's track, the ship would be positioned near the center of the track at the beginning of the next leg.

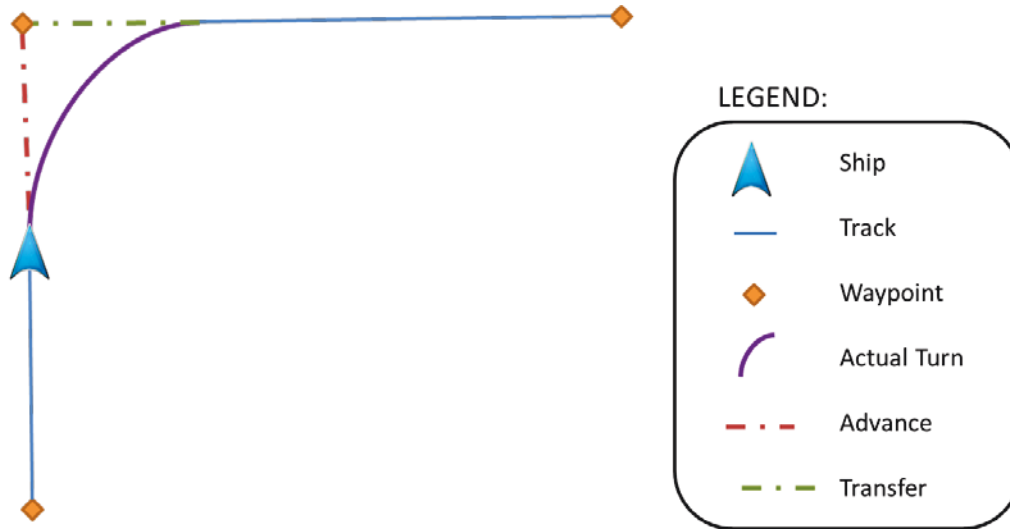


Figure 12. Advance and Transfer

A final function built into the waypoint system was the inclusion of set and drift values for each turn. Although the mechanics for implementing set and drift were executed in the physics system, the waypoint system was in charge of updating the set and drift for each course leg. One thing that was not programmed into the system was the accountability for set and drift in the turn recommendations. Current navigation systems can use known set and drift conditions to provide more accurate recommendations of when to make a turn and at what course conning officers should drive to compensate for significant wind and sea (ocean) currents. We purposefully did not include this calculation in our system to require the conning officers to actively work and compensate for the set and drift themselves. This represented a reasonable expectation of any experienced conning officer, and so the task was not seen as overburdening.

j. Auto-Helmsman

During the initial testing of the system, we concluded that the manual controlled rudder was not only tiresome, but also a variable that needed to be controlled tightly. When a conning officer gives a command to come to a certain course, it is the job of a highly qualified master helmsman to take the input and manually steer the ordered course. Everything from the current underneath the rudder to the responsiveness of the

vessel can be contributing factors of how much rudder the helmsman uses to come to an ordered course. It is the job of the helmsman to quickly come to the correct course without significantly oversteering (the act of driving past an ordered course). Oversteering is a common occurrence for less experience helmsman or when a ship is sailing in obverse conditions. Mistakes of this nature can affect the correctness of performance data associated with the conning officer.

In order to accurately and consistently portray the actions of a genuine helmsman, and avoid undue influence over the performance data for conning officers, we desired an auto-steering system. Research into existing systems helped us to identify a proportional integral derivative (PID) controller (Minorsky, 1922), which is often used in engineering systems (Bennett, 1984). The main concept is that the controller, when given an ordered course and a maximum allowed rudder angle, will adjust the rudder such that the ship quickly comes to the desired course. Using an internal feedback loop it can monitor the ship's turning speed and adjust the rudder accordingly. Thus, if the ship was turning too quickly and would likely oversteer, the PID controller will apply the opposite direction of rudder to counteract these forces. This behavior mimics the act of the helmsman observing how a certain rudder change is affecting the course heading and adjusting accordingly. We conducted testing to choose the final values for the controller inputs. The end result was the design of a highly responsive auto-helmsman that, when given a course and maximum rudder angle, would quickly and consistently bring the ship to the ordered heading.

k. Controller HUD

One of the design goals was to devise an easy-to-use interface that would assist in ship driving. The focus of the operator was to be on the task at hand, rather than interacting with an overly complex control interface. The image in Figure 13 shows the overall layout of the interface used to control the ship and presents the reports that would be relayed verbally from the navigation evaluator to the conning officer. This section outlines the purpose of each segment of this interface.

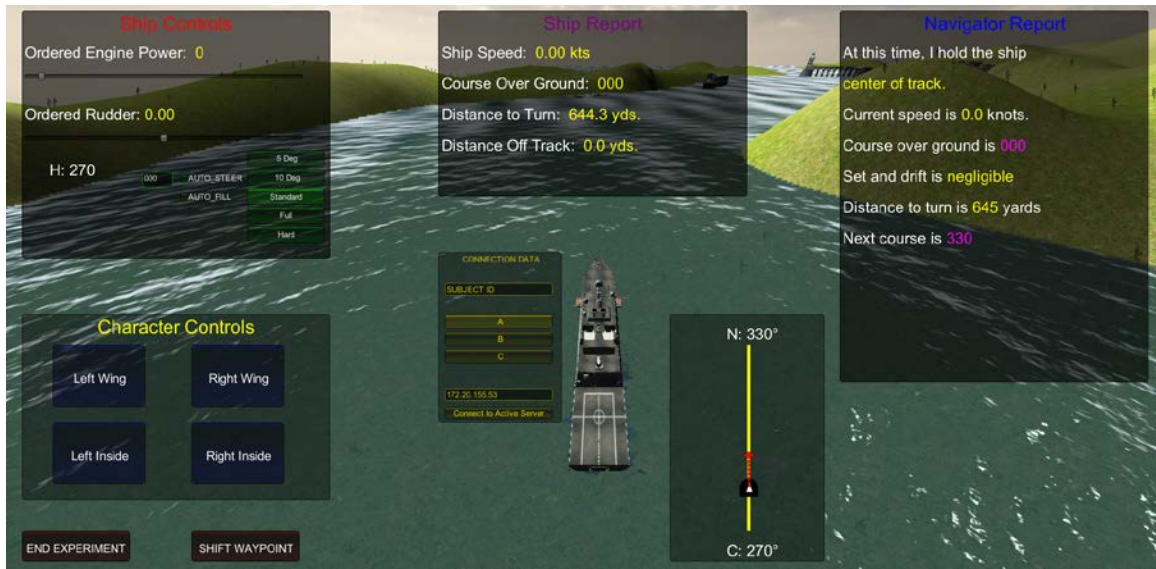


Figure 13. Controller Interface as Seen by the Operator (the Experimenter)

(1) Ship Controls

The image in Figure 14 represents the primary interface for driving the ship.



Figure 14. Ship Controls

- The “Ordered Engine Power:” this control feeds directly to the physics scripts that drive the ship. The baseline value of five was programmed so that under ideal conditions (no set or drift present) the ship would make precisely 15 knots through the water. Type: (input control)

- The “Ordered Rudder:” this control allows for manual control of the ship in occasions where the auto-helmsman system is less appropriate. An example would be when a conning officer orders a standard rudder command with no final course given. Type: (input control)
- The label titled “H: 270” is a direct value of the ships actual heading (not the course over ground). This was used to report passing headings and keep track of the auto-helmsman. Type: (system report)
- The dark text input box with “000” is a way to input the ordered course. Once the “AUTO_STEER” checkbox is checked, the auto-helmsman system takes over and turns the ship in the shortest direction toward that course. This is where the PID controller takes over and attempts to zero-in on the course requested. The “AUTO_FILL” checkbox allows the system to drive itself, receiving input on the next course from the waypoint system. This was used for testing and demonstration purposes. Type: (input control)
- The Green blocks (“5 Deg,” “10 Deg,” “Standard”=15, “Full”=30, “Hard”=35) are used as governors for the autopilot. This was put into place because conning officers can specify a maximum rudder usage during any turn. Type: (input control)

(2) Ship Report

The image in Figure 15 represents a display mechanism used to keep track of the ship’s location relative to the current leg. This capability was mostly used during the testing phases, and it was kept as a monitoring tool to ensure the navigation reports were accurate. The values presented there consisted of: (1) ship speed (unit: knots), (2) course over ground—COG (three digit number), (3) distance to turn—DTT (unit: yard), and (4) distance off track (unit: yard).



Figure 15. Ship Report

(3) Navigator Report

The image in Figure 16 provides the details of a dynamic navigation report that summarizes all of the data needed for the aural reports and formats them in a concise script. The text that was kept constantly updated was colored either yellow or purple. The numbers that are colored purple are meant to be read out individually just as they would be on the ship, e.g., 330 is read “Three, Three, Zero.”



Figure 16. Navigator Report

While the image in Figure 16 shows only one moment in time, the actual reports were dynamic and they had several different basic forms.

- “I hold the ship N1 yards (left/right) out of the turn. Current speed is N2 kts. Current course over ground is XXX. Distance to turn is N3 yds. Next course is YYY. At this time, recommend (come (Right/Left) to regain track / maintain course and speed).” —This form of the report was shown at the moment when the ship was determined to be out of the turn.
- “At this time, I hold the ship N1 yards (left of/right of/on) track. Current speed is N2 kts. Current course over ground is XXX. Distance to turn is N3 yds. Next course is YYY. At this time, recommend (come (Right/Left) to regain track / maintain course and speed).” —This report was shown every minute (500 yds) after a turn.

- “200 yards till turn” —This form of the report was shown when ship was positioned 200 yards before the turn.
- “100 yards till turn” —This form of the report was shown when ship was positioned 100 yards before the turn
- “Recommend come to course XXX” —This form of the report was shown when ship was supposed to start turning.

(4) Character Controls

The image in Figure 17 shows the interactive buttons used by the operator to move the conning officer’s viewpoint within the ship. When one of the buttons is selected, the system smoothly “walks” the viewpoint to the desired position no matter where the conning officer is currently positioned on the bridge.



Figure 17. Character Controls

(5) Network and Experiment Setup

The primary purpose of the controller displayed in Figure 18 was to establish the network connection between the host and the client. The secondary purpose was to create a text file and set the filename by concatenating the subject identifier and system condition that was ran at the time. The text input box labeled “SUBJECT ID” is where the subject’s identifier code was typed in and the selection buttons underneath corresponded to the three conditions being tested in the experiment. The box underneath allowed the operator to type in the Host IP address. The field was prepopulated with the address of the computer running the executable code and only the last triple needed to be changed (the host was configured to be on the same router).

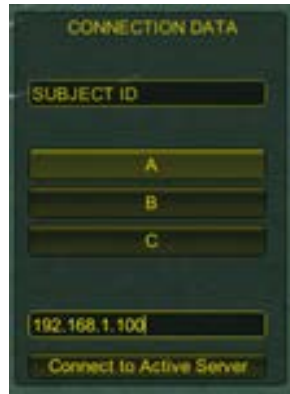


Figure 18. Connection Data

(6) Track Status Icon

The image in Figure 19 shows the tool used to assess the ship's progression on the current leg's track. The ship icon is shifted left or right of the yellow centerline, to mirror the actual ship as it moved along the track. The "N: 330°" represents the course for the next leg and the "C: 270°" is an indication of what the baseline course is for the current leg. A numerical value appears either right or left of the ship icon indicating the fact that the ship is left or right of the track.

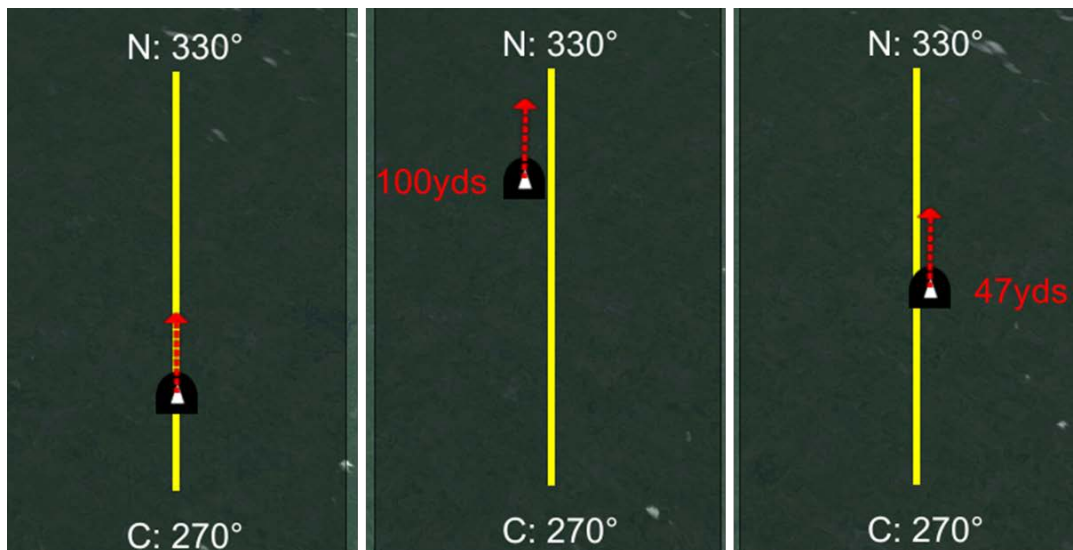


Figure 19. Track Status

(7) Emergency Buttons

The image in Figure 20 shows two interactive buttons that we designed to be used only in rare cases or in testing. The “END EXPERIMENT” button does not stop the simulation, but rather writes all the data generated until that point out to the disk. Due to the slow read/write times on the disk, all data is held in memory until the experimental session was over. The button was only meant to be used if the subject had to quit prematurely or if something went wrong with the experiment. We only had to use this button once in the entirety of the user study—in this instance, we had the subject repeat that transit.

We implemented the “SHIFT WAYPOINT” button after the test of the final system revealed a flaw in which the waypoints were not shifting automatically. This rare case only occurred when the subject was significantly off track at the end of a leg (greater than 150 yards). Actual experiment trials required the use of this button only three times out of 75 sessions.



Figure 20. Emergency Buttons

1. Conning Officer HUD

The primary purpose of the user study was to test an AR conning solution. To support that goal most effectively, designing and building the optimal solution of the HUD was an important step in the overall engineering process. The image in Figure 21 shows a screen capture of the subject’s view with the HUD deployed. As shown, the HUD consists of a series of semi-transparent indicators that present a concise navigation picture to the conning officer. The image in Figure 21 shows that even when looking at a bright sky, the numbers and letters have a good contrast against the light background and they are still perfectly legible.

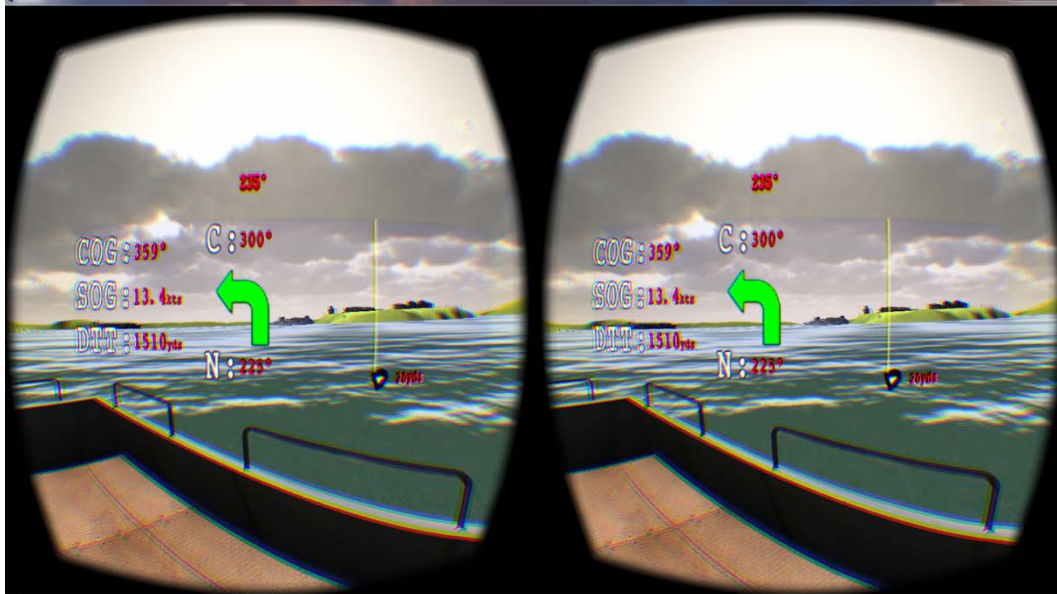


Figure 21. Conning Stereo View with HUD Deployed (Bridgewing)

The image in Figure 22 shows a screen capture of the HUD from the monitor that mirrored the images displayed in the HMD. The images of letters appear blurry due to the stereoscopic rendering that occurs during the runtime. As with the control GUI, the standard reports of COG (course over ground), SOG (speed over ground), and DTT (distance to turn) are clearly displayed. The “C:” represents the current leg’s course and the “N:” represents the next leg’s course. The yellow vertical line is a representation of the track which stays stationary relative to the HUD. The ship icon replicates the ship’s own position relative to the track. In Figure 22 the ship is 17 yards right of track and thus a red numerical display of 17 is shown just right of the ship icon. In Figure 23, the ship is 98 yards left of track and thus a green numerical display of 98 is shown just left of the ship icon. The black circle with blue numbering inside is an indicator of relative set and drift (Figure 22). The arrow coming off of it points in the direction to which wind and sea (ocean) currents are pushing the ship. The blue text inside is a numerical report of how much force is being exerted against the ship as a result of currents (unit: knots).

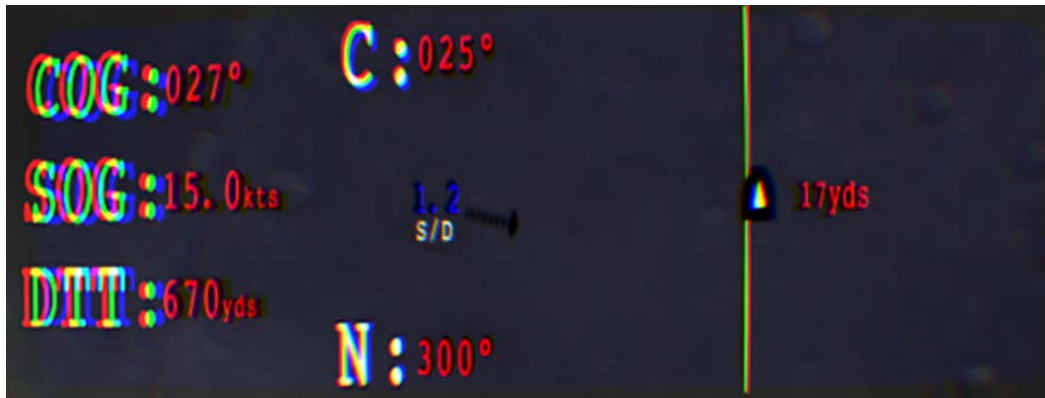


Figure 22. HUD Displaying Set and Drift

While all the data sets presented in the HUD are clear and easily distinguishable from each other (3D environment and text overlay), having the HUD constantly active during the transit would potentially lead to cognitive tunneling. Cognitive tunneling is when the human operator is focused on one layer of information while completely disregarding the content that belongs to another layer(s) of information that appears in the same space. In a real-world scenario where shipping traffic and navigation hazards are a constant distraction, a signal for an upcoming turn might not be immediately recognized. Therefore, we attempted to mitigate this possibility by actively alerting the subjects that a turn was approaching. The images in Figure 23 and Figure 24 show large arrows in the center of the HUD. These arrows flash on and off in one second increments making it more likely that the user will notice them. The yellow arrow begins flashing 200 yards before the turn and the green arrow flashes at the time of the turn. Whereas real-world notification for an upcoming turn occurs at around 1,000 yards, the compressed dimensions of the environment used in the study required shifting that to 200 yards.

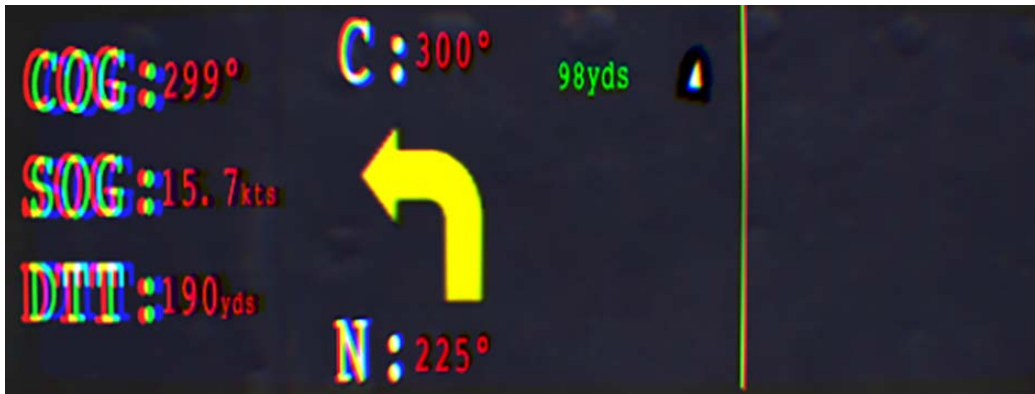


Figure 23. HUD Displaying Upcoming Turn Notification

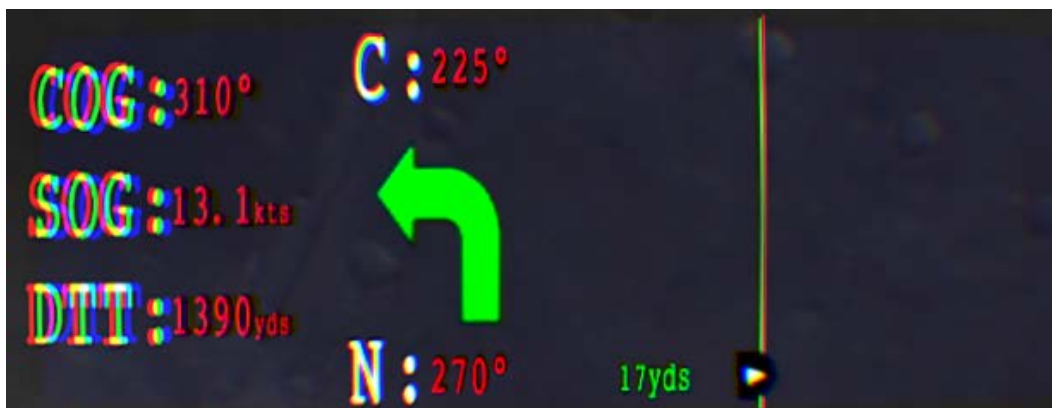


Figure 24. HUD Displaying Immediate Turn Notification

We discovered a critical problem during development. It was extremely difficult for users to read the text when looking toward backgrounds with lighter colors. The relatively low resolution of the headset combined with the outdoor lighting of the scenario made the text illegible - a lack of contrast made the text very hard to read. A solution to this problem is to use an outlined text and create sufficient amount of contrasts with any background. Unfortunately, neither the Unity game engine, nor the Oculus Rift scripts provided native capability to display outlined text. Therefore, we instead created a custom-made solution to remedy this problem. The concept, outlined in the image in Figure 25 involves writing each letter five times. The first four times, the lettering is offset by one or two pixels in each of four corner directions. The fifth print is colored in the desired font color and placed directly in the center of the letter. Because this process would be required for every single character written to the HUD, we

minimized the use of this system by employing it only for the elements that would change during the session (dynamic text elements only). The image in Figure 26 shows the file that was used as the background of the HUD to eliminate most of these calls. Rendering the single background file would take only one function call, whereas the outlined text rendering method requires several calls; reducing the number of characters that needed to be rendered this way reduced the total processing time in the final simulation.

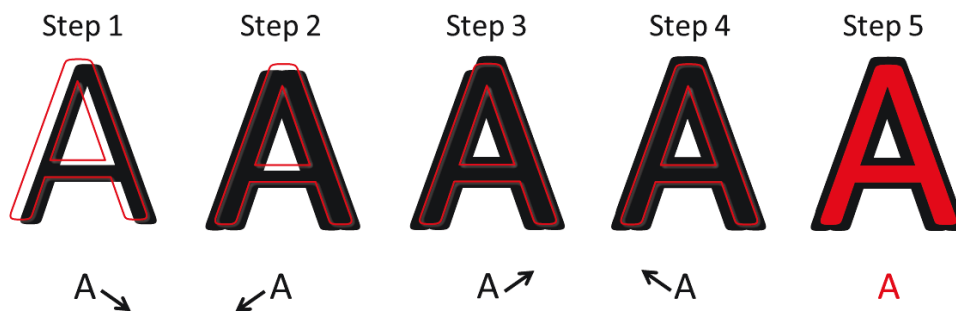


Figure 25. Outlined Text Rendering

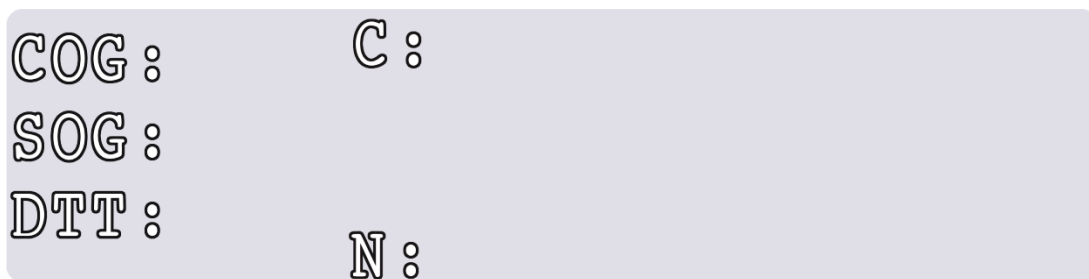


Figure 26. HUD Background Image

m. Training Scenario

Due the novelty of fully immersive VR experiences and the interactive methods employed in this study, we assumed that our user pool had little to no experience with VR simulations. Given this assumption, it was necessary to develop a training environment that would be used to teach the subjects how to navigate (move about) and perform different tasks within a VR simulation. As seen in the image of Figure 27, this

training environment represented a large virtual space with 3D objects that the subject observed and walked around in. In the scenario, the subject was asked to complete three simple tasks that had all major characteristics of the interaction modalities incorporated into the main study.



Figure 27. VR Training Simulation Overview

(1) Instructions

One task that we needed to teach each subject was to deploy (activate) the HUD. In order to impart this skill on the participants, we employed the action of tapping the mask at least four times within the training simulation. Tapping the mask resulted in the HUD textual overlay appearing in the visual field of view inside the HMD. Every time the system required the user to take action, the message shown in the image of Figure 28 was flashed inside the HUD. This forced the subjects to actively practice tapping the side of the mask with their fingers while simultaneously teaching them how much force they needed to use for successful deployment of HUD overlay.



Figure 28. Instruction Deployment Method

(2) Navigation

When the simulation first initializes, the subject is placed in the center of a large field. The environment comprises of three equally-sized zones, where each zone is reached by using a rail-navigation system. The user is asked to look around his or her environment and choose which colored zone they would like walk toward. Upon verbal request, the program operator then presses a keyboard key and the user is walked toward the declared zone.

(3) Yellow Zone

The yellow zone consists of a grey brick wall with four pictures hanging on it (Figure 29). The task is to count the number of pictures with cats on them. The purpose of this task is to force the users to look around within the environment and mentally process the scene. Although the task itself is very simple, it forces the subject to rotate his or her head and actively look around while scanning the entirety of the environment.



Figure 29. VR Training Simulation (Yellow Zone)

(4) Blue Zone

The blue zone consists of two cats placed approximately 20 and 30 feet away from the subject respectively (Figure 30). The user then begins the task of determining which of the felines is closer to them. The purpose of this is to determine if the subject is having difficulty with depth perception in the VE. As outlined in Chapter II, perceiving depth in a VE can be a challenge. Ship driving requires the ability to judge distances; therefore it is important to know if the subject has difficulty with this type of task prior to starting the primary simulation.



Figure 30. VR Training Simulation (Blue Zone)

(5) Red Zone

The red zone consists of one cat placed approximately 10 feet in front of the subject (Figure 31). The task is to use the digital compass to ascertain the bearing of the cat; a red colored number displayed in the middle of the screen, suggests the bearing of the object in the center of screen, and it gets updated dynamically as the subject moves his or her head. By performing this task, the subject learns how to use the digital compass. During the primary simulation this tool is available with or without the HUD elements, so it was important for the test subjects to familiarize themselves with its presence and purpose.



Figure 31. VR Training Simulation (Red Zone)

C. SUMMARY

The purpose of this chapter was to present the process of creating the environment and the different solutions needed for the study, including the solutions that had to be abandoned, and act as a guide for those who might go through creation of a similar system. The technical highlights of the simulation were the use of a PID controller for the helmsman, the simplistic programming approach to outlining text when no functions are natively available, and the seamless integration of a brand new HMD with few code repositories. There were many points along the way where a simpler, good-enough, and faster-to-code solution was chosen over a solution that would have been more true to the real-world physics. The purpose of the study was to test a very specific idea and not to invest a disproportional amount of time to build an accredited ship driving simulator. We ensured that the display frame rate remained around 75 FPS—this was done to avoid a possibility of symptoms of cybersickness caused by low frame rate. This goal was achieved by limiting the number of in-game objects in 3D environment. The officers and engineers who either tested our system or took part in the study had overwhelmingly positive reviews of the level of realism presented in the environment which meant that the variety and the number of objects in the scene were satisfactory; this type of feedback justified the design decisions that had to be made along the way.

V. USABILITY STUDY AND DATA ANALYSIS

This chapter details the user study and accompanying results. Sections in this chapter review the subject pool, the experimental methodology, and the scenario used in the study. The data sets that were analyzed include empirical measurements (objective data set), subjects' questionnaires, and interviews. The software tools utilized for the statistical analysis of collected data were JMP Pro Version 11 and Statistica Version 10.

A. SUBJECTS

The study engaged highly specialized subjects with a very specific skill set. While the U.S. Navy does not require any actual certification for standing the watch of conning officer, the skill set required to carry out the role is not one that can be mastered overnight. Early on in the development phase of this user study, we established that testing would occur in institutions with significant population of surface warfare officers. By recruiting subjects in these places, we were able to acquire enough qualified candidates to make the data we gathered statistically relevant. Testing occurred in December of 2014 at Surface Warfare Officer School (SWOS), Newport, Rhode Island. A second round of testing occurred at NPS, Monterey, California in January of 2015.

Contact was made with SWOS leadership early in the development phase; it was agreed that we would not only utilize their expertise, but would also seek consent to conduct experimentation at the schoolhouse. As SWOS is the U.S. Navy's primary schoolhouse for the training of ship drivers, it is also a very logical place to test new ship driving concepts. With the approval from SWOS leadership to recruit their students and instructors for our study, Institution Review Board (IRB) approval was promptly applied for. The IRB granted approval, and we began to advertise for the study through email announcements, personal exchanges, and recruitment flyers—the text of the flyer is enclosed in Appendix A. We traveled to Newport, RI for one week to conduct the study. By the end of the week, we had 12 volunteers for the study.

We performed a second series of tests at NPS. Similar to the segment of the study done at the SWOS, we recruited experienced surface warfare officers at NPS. By

advertising to the NPS surface warfare officer group via email and on the NPS daily muster page we were able to recruit a total of 13 subjects, and complete all sessions within one week.

We asked each of the 25 subjects to fill out a personal and professional history survey at the beginning of the study (Appendix B). Although the study was advertised to both sexes, all of our subjects were male. The information in Table 2 shows the distribution of the age amongst the subjects. The average age was 30.56 years old with a standard deviation of 3.69 years. The youngest subject was 25 years old and the oldest was 39 years old.

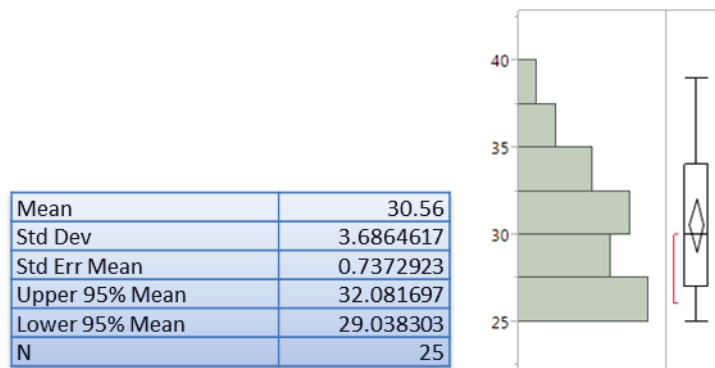


Table 2. Subject Age

Eighty-eight percent of the subjects were professionally designated as surface warfare officers (22 out of total 25). The remaining three subjects (12% of our sample) were designated as information professional officer, engineering duty officer, and deck surface limited duty officer respectively. Ninety-six percent of the subjects held the rank of lieutenant or O3. One subject was a lieutenant junior grade; in this case the subject was prior enlisted and thus classified as an O2E. The information in Table 3 indicates the distribution of years of active duty service for each subject. The average years of active duty service was 9.48 years with a standard deviation of 5.42 years. The minimum years of active duty service was 4 and the maximum was 20.

Mean	9.48
Std Dev	5.4227146
Std Err Mean	1.0845429
Upper 95% Mean	11.718387
Lower 95% Mean	7.2416134
N	25

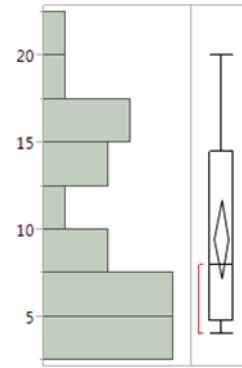


Table 3. Years of Active Duty Service

The information in Table 4 indicates the distribution of years served while designated as a 1160/1800, the U.S. Navy designations for qualified/unqualified surface warfare officers. While some of the subjects may have served in the U.S. Navy for many years, this statistic gives an indication of how much time they would have spent in the surface warfare community. The average number of years as a 1160/1800 designation was 5.22 years with a standard deviation of 1.8 years. The minimum years reported was zero and the maximum was eight years. The subject that reported having served zero years in the designation had been prior enlisted for over a decade and had been previously designated as a boatswains mate. This enlisted rating is one of the primary rates responsible for driving the ship and thus his experience level was equivalent, if not better, than the other subjects.

Mean	5.22
Std Dev	1.8261982
Std Err Mean	0.3652396
Upper 95% Mean	5.9738176
Lower 95% Mean	4.4661824
N	25

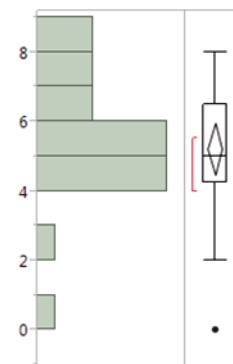


Table 4. Years Designated as 1160/1800

The average time since each subject had stood the watch of conning officer was 18.76 months with a standard deviation of 16.55 months. The minimum time since last conning was zero months and the maximum was 72 months. The average time since each subject had last stood the watch of conning officer during a restricted maneuvering operation was 21.96 months with a standard deviation of 20.44 months. The minimum time since last conning during a restricted operation was zero months and the maximum was 72 months. The information in Table 5 shows the distribution of the number of times each subject estimated they had stood the watch of either OOD or conning officer while transiting into or out of port. The average number of transits was 29.38 with a standard deviation of 21.17 transits. The minimum was zero transits and the maximum was 100. One subject did not choose to answer this question (N = 24 for this question).

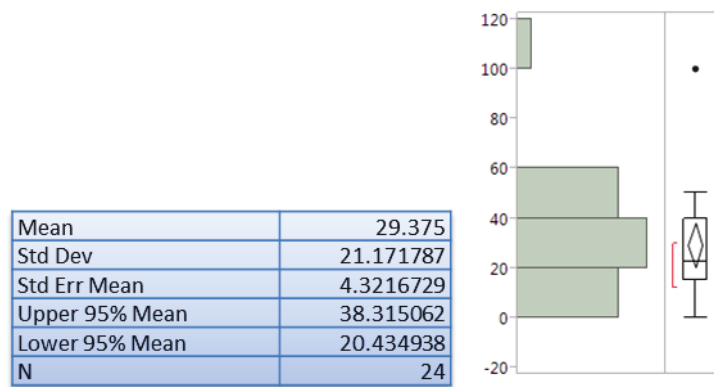


Table 5. Times OOD / Conn out of port

Out of the 25 subjects, 6 individuals (24.00%) had been qualified as a navigator or assistant navigation officer. For those who had been qualified, the average time serving in that position was 1.64 years with a standard deviation of 2.17 years. Of the 25 subjects, 19 individuals (76.00%) had served onboard an ECDIS-N certified ship. For those who had done so, the average time since being onboard was 2.05 years with a standard deviation of 1.83 years. When asked to rate their current skill level at conning ships, the subjects were given five categorical levels to choose from. These were: Bottom 5%, 35 50%, 50 75%, 75 95%, and Top 5%. Of the 25 subjects, 6 individuals (24.00%) reported themselves at the 50%-75% percentile, 12 individuals (45%) reported themselves at the

75–95% percentile, and seven individuals (28.00%) reported themselves at the top 5.00%.

Of the 25 subjects, 15 individuals (60.00%) reported that they play video games. The distribution of game types they play is shown in Table 6. The most commonly played games were first-person shooters (56.00%) and adventure/fantasy/role-playing (36.00%). The most common platform for playing video games was a game console followed by a computer.

GAME TYPE \ SYSTEM	Computer		Smartphone		Tablet, Ipad		Game Console		Other Cellphone	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
First Person Shooter	7	28.00%	0	0.00%	0	0.00%	11	44.00%	0	0.00%
Online Multiplayer	5	20.00%	0	0.00%	0	0.00%	4	16.00%	0	0.00%
Adventure, Fantasy, Role Playing	6	24.00%	0	0.00%	0	0.00%	5	20.00%	0	0.00%
Other:	6	24.00%	2	8.00%	1	4.00%	3	12.00%	1	4.00%

Table 6. Subject Video Game Practice

The survey given included a section about previous experience with simulators. Every subject reported having prior experience with simulators and 24 of 25 (96.00%) reported having used COVE at some point in their career. For those who reported having used COVE, the information in Table 7 indicates the distribution of the number of hours utilizing the trainer. The average time since last use was 19.34 months with a standard deviation of 20.16 months. The second highest reported simulator was the FMB with 10 of 25 subjects (40.00%) reporting that they had used the system. The average time spent in the FMB was 44.90 hours with a standard deviation of 63.06 hours and the time since last use average was 25.89 months with a standard deviation of 17.67 months. Other reported simulators included an LCS trainer, a point defense trainer for small boat operations, and a VMS trainer.

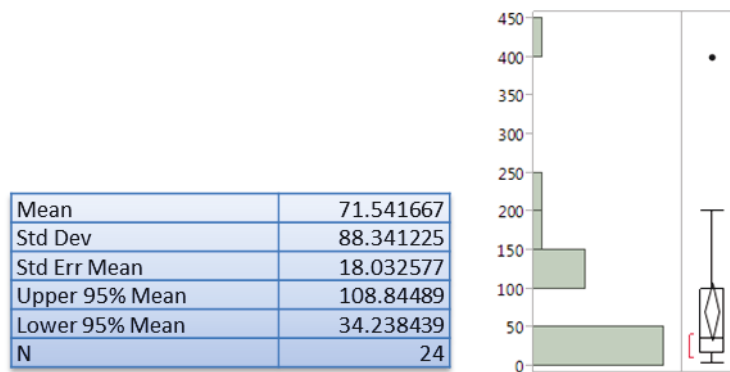


Table 7. Hours Using COVE

Of the 25 subjects surveyed, 24 individuals (96.00%) reported having used an HMD before and only one (4.00%) reported having used an AR display.

B. STUDY DESIGN

The goal of the study was to determine the viability of an operational setup of the bridge onboard U.S. Navy warships, in which a conning officer's visual field is augmented with an overlay of CNI that is typically relayed in aural form from the navigation officer. This work specifically targeted the bridge experience during a restricted navigation transit.

1. Physical Environment

For both the SWOS and the NPS testing cycles, we kept the physical setup of computers, participants, and desks the same. The subject filled out paperwork at a nearby desk in the room. The subject then did all VR sessions while standing in front of a large desk with two computers and two monitors atop it. As shown in the image in Figure 32, the simulated helmsman and navigation evaluator stood behind the desk and the subject (conning officer) stood in front of it. We left enough of a gap in between the monitors to physically observe the subject for outward signs of cybersickness. The desk also gave the subjects something to hold onto in the case of disorientation during the sessions. The images in Figure 33 and Figure 34 show the physical layouts of personnel and equipment at both SWOS and NPS respectively. The image in Figure 35. shows all the peripheral equipment used in the study.

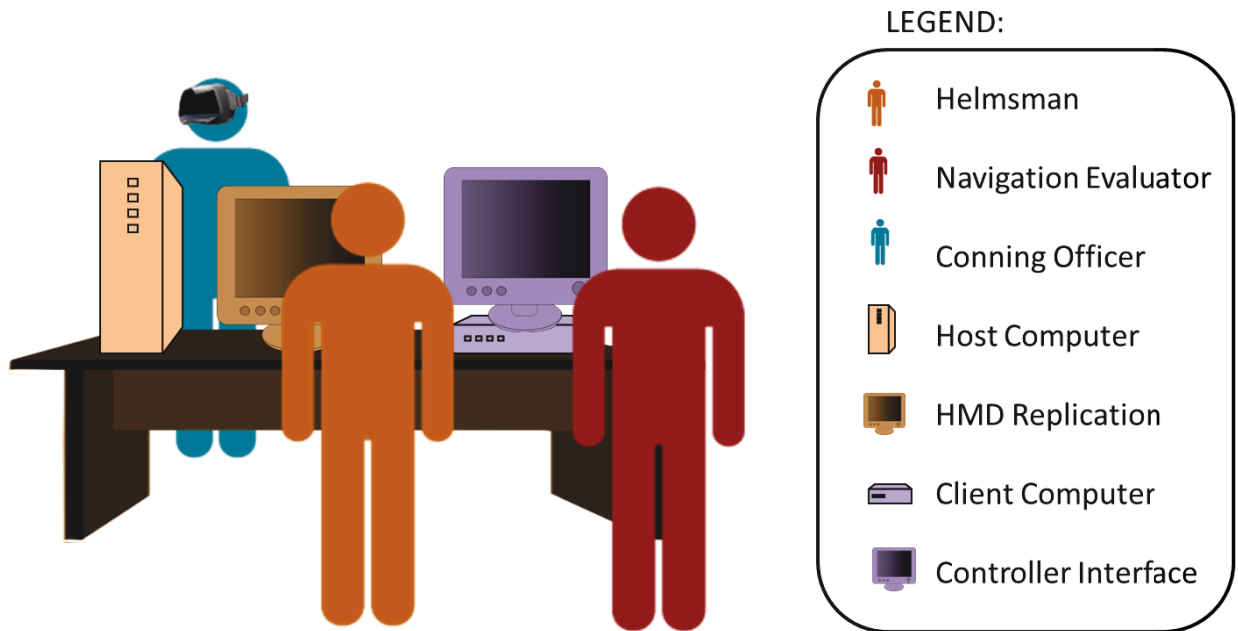


Figure 32. Physical Study Environment Layout



Figure 33. Physical Study Environment (SWOS)

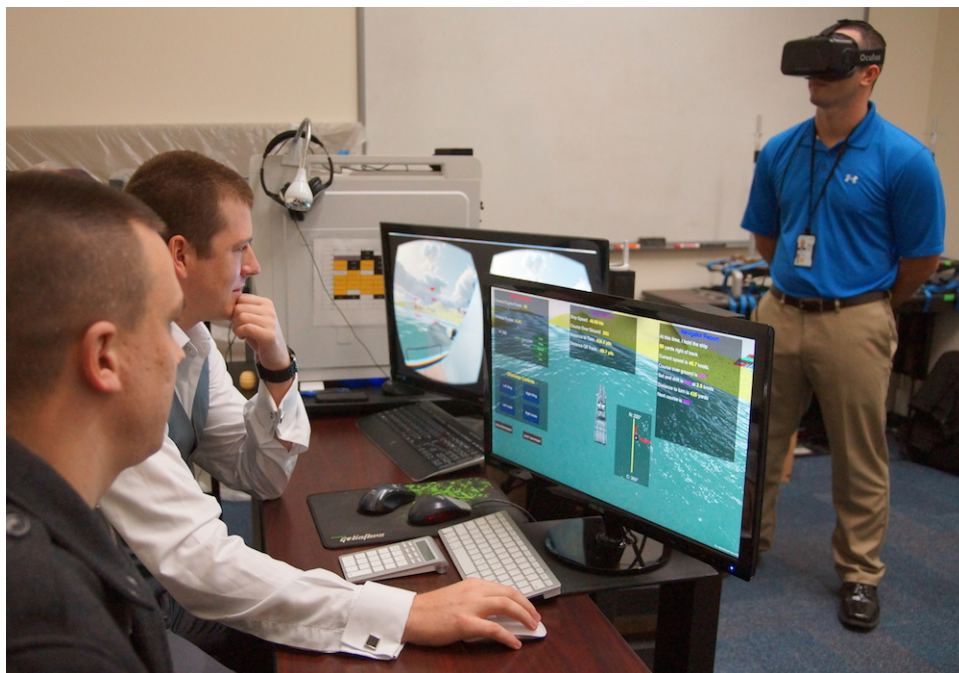


Figure 34. Physical Study Environment (NPS)



Figure 35. Physical Study Equipment

2. Support Staff (Experimenters)

During the study, two researchers played the parts of a helmsman and a navigation evaluator. A trained officer with intimate knowledge and experience of real-world ship driving acted as the helmsman. This officer accurately portrayed a helmsman through accurate repeat-backs and quick actions in manipulating the ship. The part of the navigation evaluator was played by a team member who had been trained to read the automatically updated scripts (detailed in Chapter IV) and also provide additional reports as needed based on the information available. At both SWOS and NPS, the exact same two individuals performed these tasks for all sessions for all subjects, which provided a consistent input and conditions for all subjects.

3. Experimental Conditions

In this experiment, subjects conned ships using the NAVHUD ship driving simulation described in Chapter IV. In order to test the hypotheses outlined in Chapter I, each subject conducted three transits out of the same channel in each condition (within-subjects study design). We counterbalanced experimental conditions to avoid learning-effects influencing results. There were three experimental conditions tested in user study:

A: Navigation Evaluator (CNI provided in auditory form only): The subject received only auditory reports by a trained experimenter who played a role of a navigation officer.

B: Navigation Evaluator + HUD (CNI provided in both auditory and visual form): The subjects received auditory reports in addition to visual information (overlaid in their visual field) presented inside a heads-up display. This augmented layer is the conning officer HUD detailed in Chapter IV.

C: HUD (CNI provided in visual form only): The subject received only the HUD elements, i.e., visual information as detailed in Chapter IV.

4. Description of Ship Navigation Course

Described in Chapter IV, we specifically built the fictitious channel created during the design phase to provide useful data for the study. Table 8 provides the details about each leg within the transit out of the channel. Figure 36 pictorially represents the same data but overlays each leg onto a chart. The ship started each session on Leg 0 at a standstill pointing in the correct direction of transit. When the subject was ready to begin, the experimenter acting as helmsman, brought the ship up to speed. For the purposes of data review, we collected Leg 0 data but did not consider it in the final data analysis. This is because the ship started on track and the conning officer needed to take no action to keep it that way. Data from Leg 1 was the first that we used. To give the conning officers a slight acclimation period to how the ship handled, Leg 1 did not include any current to drive the ship off course. The rest of the track had current that changed in direction and speed for each new leg. Each leg, with the exception of the starting leg, was 1,500 yards long.

Leg	Course	Distance	Direction of Currents	Speed of Currents
0	270	1000 yds	-	0.0 kts
1	330	1500 yds	-	0.0 kts
2	025	1500 yds	125	1.2 kts
3	300	1500 yds	230	2.5 kts
4	225	1500 yds	135	2.0 kts
5	270	1500 yds	000	1.7 kts

Table 8. Outbound Transit Leg Details

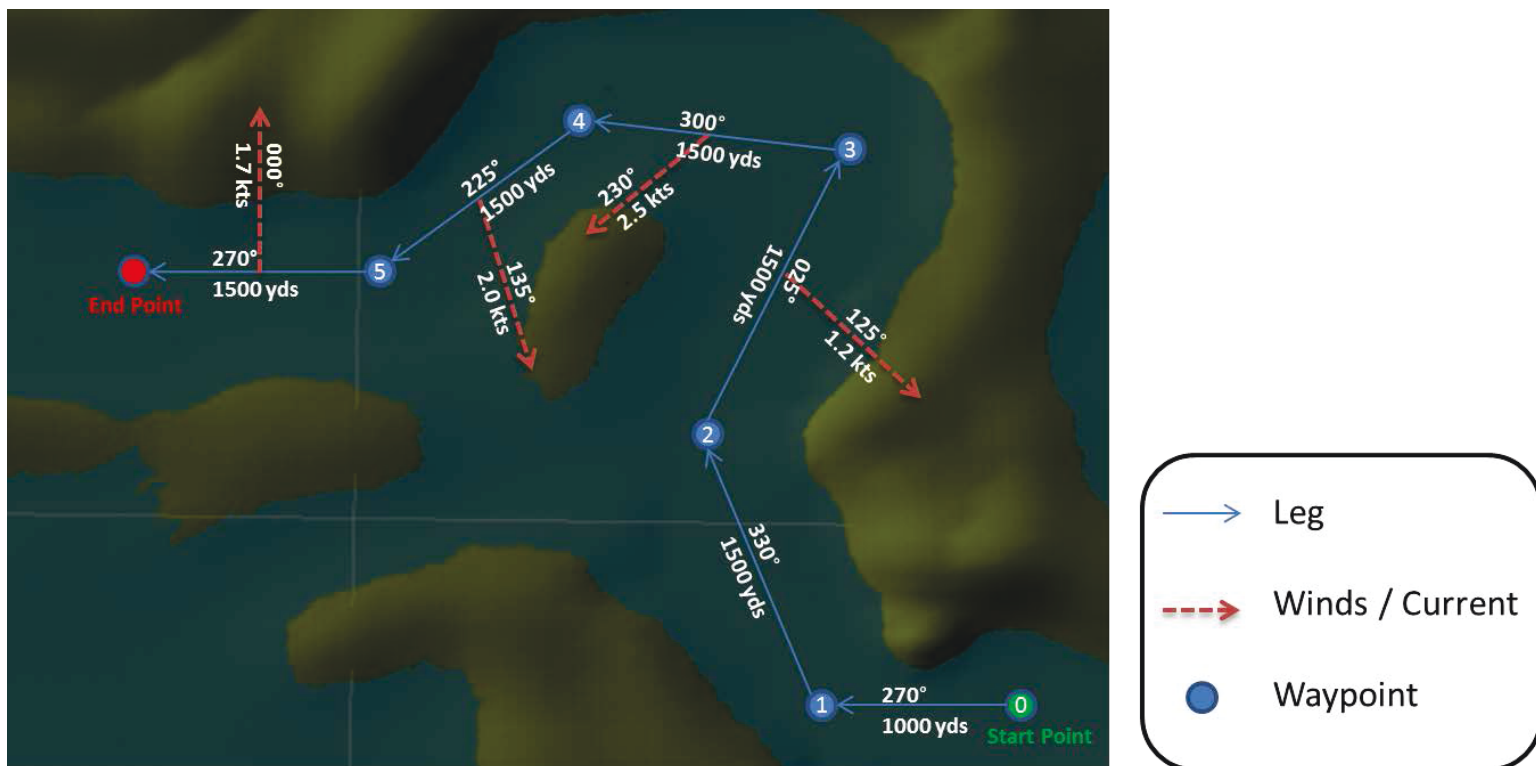


Figure 36. Outbound Transit Chart with Legs and Currents

5. Bridge Positions

As described in Chapter IV, the study allowed the subjects to move to several positions on the bridge. The positions in the study included two “centerline” positions (middle of the bridge) and the left/right bridge wings positions respectively. The conning officers were required to verbally ask the helmsman to move between the four possible positions on the bridge: the left bridge wing, the right bridge wing, the left-center bridge, and the right-center bridge. The image in Figure 37 depicts a view from the left bridge wing (Position A), the image in Figure 38 depicts a view from the left-center bridge (Position B), the image in Figure 39 depicts a view from the right-center bridge (Position C), and the image in Figure 40 depicts a view from the right bridge wing (Position D).

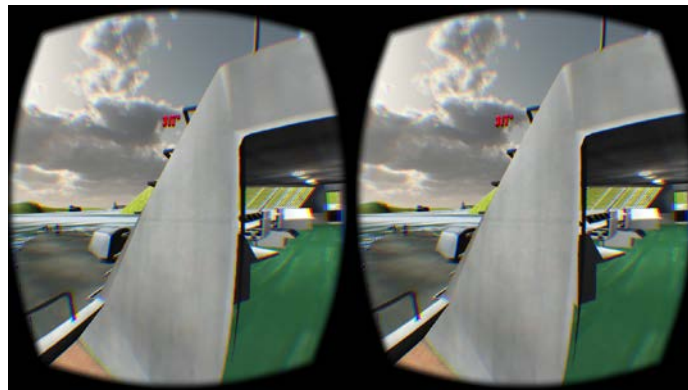


Figure 37. Stereo View from Left Bridge Wing Position

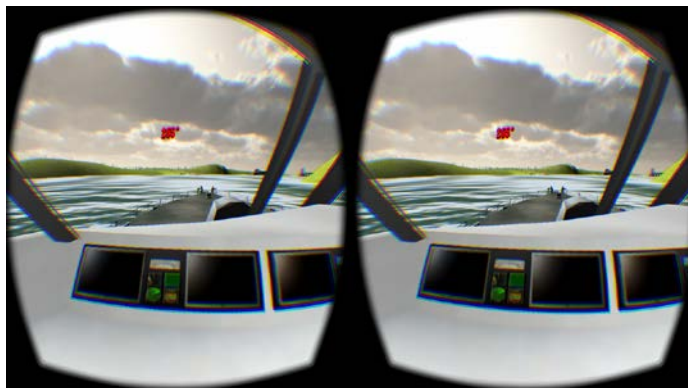


Figure 38. Stereo View from Left-Center Bridge Position

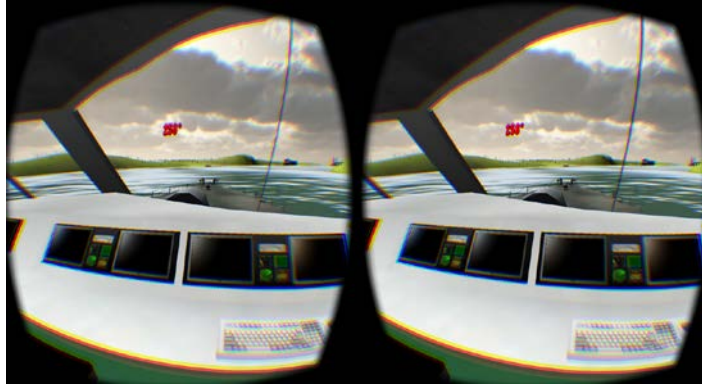


Figure 39. Stereo View from Right-Center Bridge Position

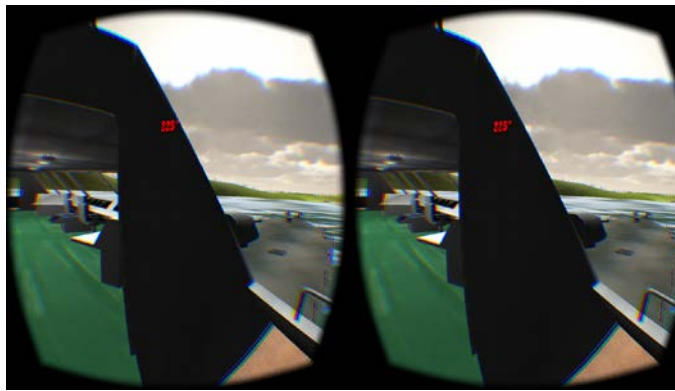


Figure 40. Stereo View from Right Bridge Wing Position

6. Collection of Objective Data Set

The simulation recorded data for each subject in three separate files, each corresponding to one experimental condition. Data recorded included the following elements: (a) performance data (distance from the track), (b) instances when the HUD layer was deployed, i.e., turned ON or OFF, and (c) subject's position on the ship's bridge (including instances when that position was changed). The simulation recorded snapshots of data at even distance intervals for each subject. During each leg, the simulation constantly calculated DTT, which determined when to take data measurements. When the ship began each leg, the initial value of DTT would be slightly less than 1,500 yards due to advance and transfer calculations. As the ship approached the upcoming turn, that DTT would approach zero and then reset to approximately 1,500 yards again once the turn started. Every ten yards, the simulation recorded the current

position of the ship. In the real world, as the ship turns, there is no way to instantly determine whether it is left or right of track; this led us to decide not to begin taking measurements until the DTT reached 1,350 yards, i.e., when we were confident that the ship had completed the turn and was on a steady course.

7. Collection of Subjective Data Set

Throughout the study, we collected subjective data from each subject. These included: (1) standard simulator sickness questionnaire (SSQ) (Appendix D) at the beginning of the study (to form a baseline SSQ data set) and after each instance in which they donned the HMD, (2) opinion questionnaires were given after each session with the HMD (Appendix E), and (3) an exit interview. The goal of collecting a subjective data set was to supplement the objective data with information that explained or clarified the final results. Knowing that the performance gains were registered in one experimental condition over the others, for example, would not explain the reason why that happened. The subjective data also gave us additional indicators of user preferences, which the U.S. Navy can use in deciding whether an option warrants adaption. As our secondary hypothesis deals with the end-users acceptance and integration of AR into daily operations, we needed a subjective data set to make assertions on this.

C. METHODOLOGY

We centered the study on immersing the subjects in the VR environment described in Chapter IV and measuring their performance. Additionally, throughout the study, we collected cybersickness surveys, questionnaire data, and interview data. We used the checklist in Appendix F to ensure all steps were taken for each subject and in exactly the same order. The following list presents a detailed description of stages that each subject experienced in the study.

1. Pre-Experiment

The subject filled out an IRB informed consent form and audiovisual consent form (Appendix C). They then filled out a background questionnaire and a simulator-sickness questionnaire (Appendix D). The questions included: demographic data,

information about past experiences within the study domain, past experience with computer-supported simulations, and an estimate of their skill levels relevant to the study. This process took approximately five minutes.

2. Virtual Environment Training Scenario

The subject then donned a head mounted display (HMD); once the device was comfortably fitted, an acclimation simulation with a training scenario was started (details provided in Chapter IV). This simulation enabled the subject to become comfortable with navigating through, and interacting with, a VE using the same interaction modalities that are needed in the main study. The environment was a representation of a large virtual space with three-dimensional objects that the subject observed and walked around in. In this scenario, the subject performed simple navigational tasks and interaction modalities that consisted of major characteristics from the main study. The subject had up to ten minutes to accomplish three tasks in the training environment; after which, he removed the headset and answered a SSQ. This process took approximately 15 minutes. 25 of 25 subjects (100%) had no difficulty with the training simulation and successfully completed all required tasks.

3. Main Experiment

The subject read the information about the task he would be completing in the upcoming scenario from the data sheet included in Appendix G. The sheet briefed the subject on vessel characteristics, engine orders, rudder orders, internal navigation procedures on the bridge, and the overall transit plan. The transit plan detailed the expected courses, turns, and speeds of the transit. We gave each subject as much time as necessary to study the transit and to ask questions about the environment—no subject spent more than five minutes to complete this. After a subject reported being comfortable with the transit plan and ship specifications, he was then given an instruction script that depended on which scenario variation was presented first. This script outlined the task, the situation, and the mode of navigation reports that were provided in the given experimental condition (Appendix H). On starting the simulation, the subject donned the HMD once more.

Upon donning the HMD, the subject conned the vessel along the track. Each transit took approximately 15 minutes. After the ship had crossed the finish point, the subject removed the HMD and filled out a survey that captured the subject's opinions on the overall experience as well as elements of SSQ, which took approximately five minutes.

The subject repeated this entire process twice to account for each of the three experimental conditions outlined in the study design. Each time the subject was briefed, conducted a transit out of the channel, and filled out a survey of their experience within a particular scenario as well as a SSQ. The entire process, including the accompanying paperwork, took 1 hour and 5 minutes per subject.

4. Post Experiment

The subject filled out an exit survey of his experiences (Appendix E). In addition, we conducted a short interview to garner opinions that were not captured in the survey and the subject was given a debriefing form (Appendix I).

D. RESULTS

1. Objective Data Set

This section presents a summary of the analysis done on the objective data set that we collected during the study. The data set includes: (1) conning officer performance data, (2) conning officer bridge position analysis, and (3) HUD deployment tracking analysis. The tables in Appendix J show the distribution of conning officer performance per condition. Under Condition A, conning officers averaged 31.90 yards off track. Under condition B, conning officers averaged 17.41 yards off track. Under condition C, conning officers averaged 14.80 yards off track. In order to determine the statistical difference between groups we needed to run an analysis of variance (ANOVA). This was determined to be an unsuitable solution due to the data not having normality. This lack of normality is shown in distribution graphs in Appendix K. In order to compensate for the lack of normality of the data, we ran Mann-Whitney U Tests between each of the conditions. The greatest significance appears between Conditions A and B and

Conditions A and C. The information in Table 9 and Table 10 show that all legs, with the exception of Leg 1, have p-values less than .005. Leg 1 has less significant difference in performance due to the lack of currents on that leg. The relative ease of that leg resulted in all conditions reporting similar performances. The information in Table 11 shows the analysis between Conditions B and C. The p-values in this case average above .05—indicating a lack of significance between the conditions. Since both Conditions B and C utilized the HUD and Condition A did not, we summarize that the HUD was the significant factor in an increase of performance per session. This indicates that the reported averages are statistically significant enough to reject the null hypothesis presented in Chapter I.

- H_{10} : A lightweight glasses-type AR overlay system for a conning officer does not increase his ability to maintain a close proximity to a preplanned track.

Rejecting H_{10} does not prove our alternate hypothesis, but it does indicate that the HUD had a positive effect on the conning officer's overall performance.

variable	Mann-Whitney U Test (NPS Augmented Reality Conning Officer Performance Study CompressedData-averagesPerTrack-2015-02-23) By variable Session Marked tests are significant at p <.05000									
	Rank Sum A	Rank Sum B	U	Z	p-value	Z adjusted	p-value	Valid N A	Valid N B	2*1sided exact p
Track 1	707.0000	568.0000	243.0000	1.338797	0.180638	1.338797	0.180638	25	25	0.182269
Track 2	784.0000	491.0000	166.0000	2.832816	0.004614	2.832816	0.004614	25	25	0.003972
Track 3	880.0000	395.0000	70.0000	4.695490	0.000003	4.695490	0.000003	25	25	0.000000
Track 4	799.0000	476.0000	151.0000	3.123859	0.001785	3.123859	0.001785	25	25	0.001393
Track 5	802.0000	473.0000	148.0000	3.182067	0.001462	3.182067	0.001462	25	25	0.001114

Table 9. Conning Officer Performance (Condition A versus Condition B)

variable	Mann-Whitney U Test (NPS Augmented Reality Conning Officer Performance Study CompressedData-averagesPerTrack-2015-02-23) By variable Session Marked tests are significant at p <.05000									
	Rank Sum A	Rank Sum C	U	Z	p-value	Z adjusted	p-value	Valid N A	Valid N C	2*1sided exact p
Track 1	577.0000	698.0000	252.0000	-1.16417	0.244356	-1.16417	0.244356	25	25	0.246748
Track 2	838.0000	437.0000	112.0000	3.88057	0.000104	3.88057	0.000104	25	25	0.000050
Track 3	861.0000	414.0000	89.0000	4.32684	0.000015	4.32684	0.000015	25	25	0.000004
Track 4	865.0000	410.0000	85.0000	4.40445	0.000011	4.40445	0.000011	25	25	0.000003
Track 5	865.0000	410.0000	85.0000	4.40445	0.000011	4.40445	0.000011	25	25	0.000003

Table 10. Conning Officer Performance (Condition A versus Condition C)

variable	Mann-Whitney U Test (NPS Augmented Reality Conning Officer Performance Study CompressedData-averagesPerTrack-2015-02-23) By variable Session Marked tests are significant at $p < .05000$									
	Rank Sum B	Rank Sum C	U	Z	p-value	Z adjusted	p-value	Valid N B	Valid N C	2*1sided exact p
Track 1	520.0000	755.0000	195.0000	-2.27013	0.023200	-2.27013	0.023200	25	25	0.022262
Track 2	716.0000	559.0000	234.0000	1.51342	0.130173	1.51342	0.130173	25	25	0.131021
Track 3	683.0000	592.0000	267.0000	0.87313	0.382594	0.87313	0.382594	25	25	0.385853
Track 4	750.0000	525.0000	200.0000	2.17312	0.029772	2.17312	0.029772	25	25	0.028881
Track 5	751.0000	524.0000	199.0000	2.19252	0.028343	2.19252	0.028343	25	25	0.027439

Table 11. Conning Officer Performance (Condition B versus Condition C)

The charts in Figure 41, Figure 42, and Figure 43 indicate the averages of how well conning officers performed for each leg—experimental condition being the variable factor between charts. The graphics separate the performance by colors where dark green indicates the subjects were less than 10 yards off track and dark red indicates they were over 100 yards off track. The other colors are clearly labeled in the legend. Leg 0 data is not displayed because the initial starting leg placed the subjects in the center of the track and required no external manipulation to maintain the course—under every condition the bar would be pure dark green. There is little disparity in Leg 1 because of the ease of that leg—due to a lack of currents. From Leg 2 forward, the separation of performance becomes clear. In all session, Leg 3 proved to be the most difficult: in the graphs this can be seen by the fact that the lowest percentage of dark green occurs on that leg. By reviewing all three graphs, a clear delineation of which conditions saw better performance from the subjects can be seen. Conditions B and C doubled the amount of time within the zero to ten yards zone then Condition A. Compiling the data from the information in Figure 41, Figure 42, and Figure 43, we calculate that the actual time on track for each condition as: 31.43% (Condition A), 47.10% (Condition B), and 54.67% (Condition C). This indicates that, when given the option of having the data presented in the HUD, subjects stayed less than ten yards off track 61.76% more of the time.

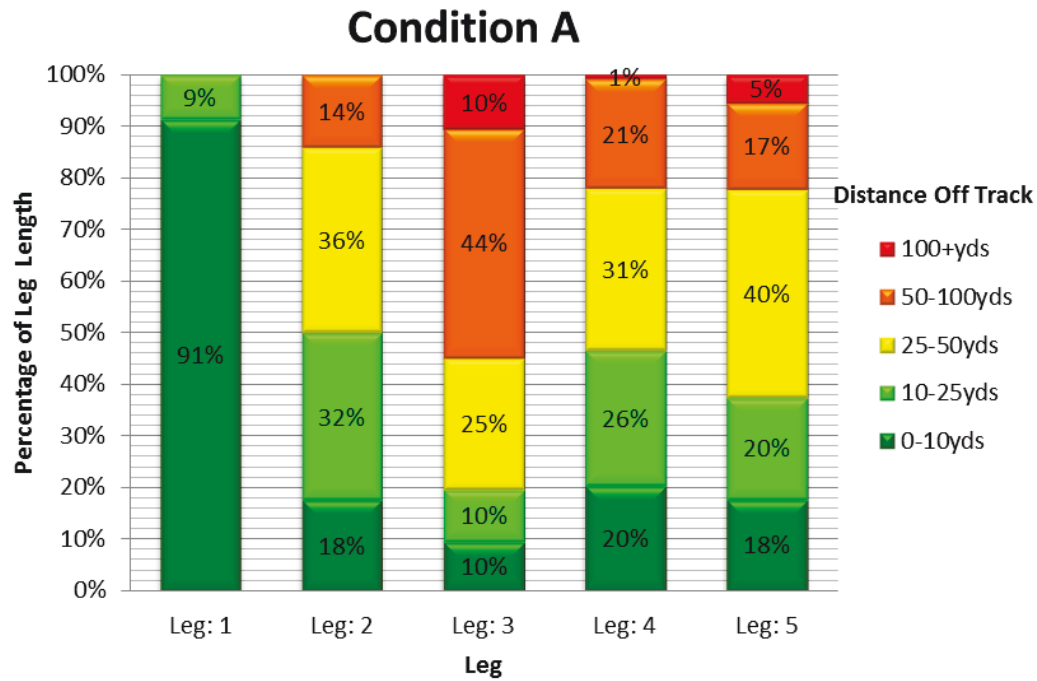


Figure 41. Subject Performance per Leg: Condition A

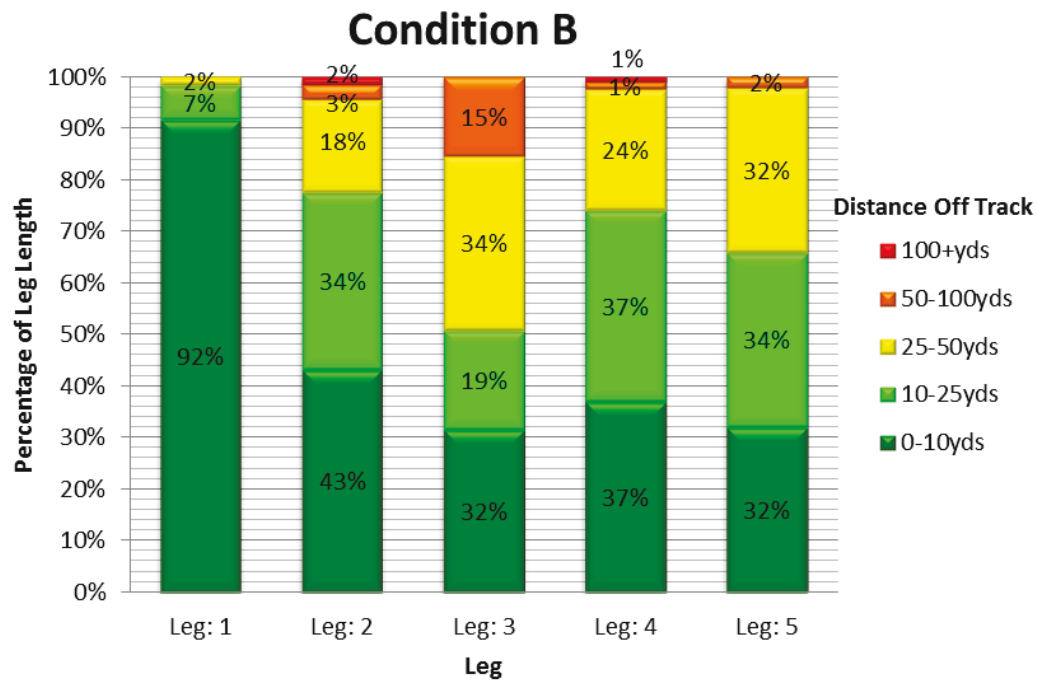


Figure 42. Subject Performance per Leg: Condition B

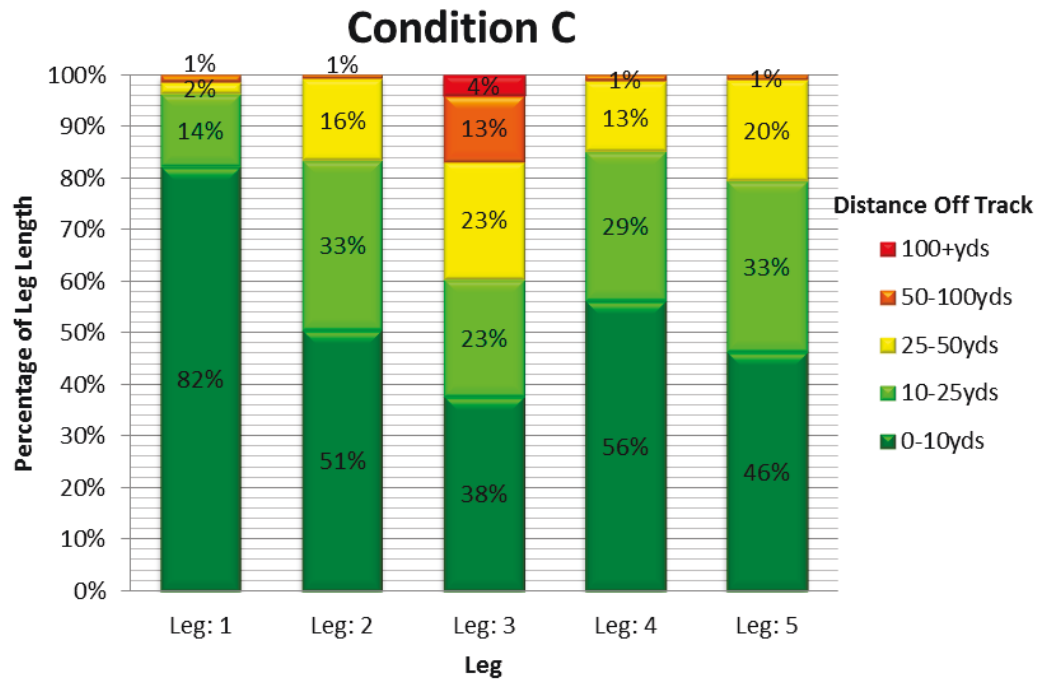


Figure 43. Subject Performance per Leg: Condition C

The information in Table 12 shows the distribution of how many times a subjects activated the HUD during Condition B. The results indicate that, during Condition B, the subject activated the HUD an average of 4.52 times per transit with a standard deviation of 5.29 times. The information in Table 13 shows the distribution of how many times a subjects activated the HUD during Condition C. The results indicate that, during Condition C, the subject activated the HUD an average of 5.00 times per transit with a standard deviation of 10.07 times. The information in Table 14 shows the distribution of how many times a subject activated the HUD over both Condition B and Condition C. The results indicate that, on average, the subject activated the HUD 4.76 times per transit with a standard deviation of 8.34 times. One subject activated the HUD 51 times and 19 subjects activated the HUD only once during a session, which suggests that they chose to keep it deployed for the entirety of the transit.

Mean	4.52
Std Dev	5.2924474
Std Err Mean	1.0584895
Upper 95% Mean	6.7046149
Lower 95% Mean	2.3353851
N	25

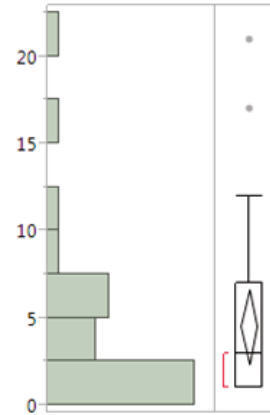


Table 12. HUD Activation: Condition B

Mean	5
Std Dev	10.665365
Std Err Mean	2.1330729
Upper 95% Mean	9.4024461
Lower 95% Mean	0.5975539
N	25

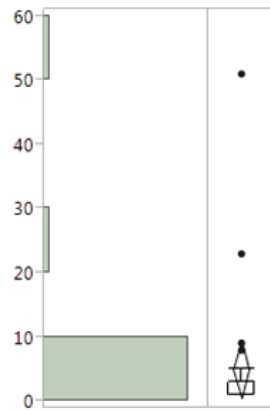


Table 13. HUD Activations: Condition C

Mean	4.76
Std Dev	8.3362009
Std Err Mean	1.1789168
Upper 95% Mean	7.1291221
Lower 95% Mean	2.3908779
N	50

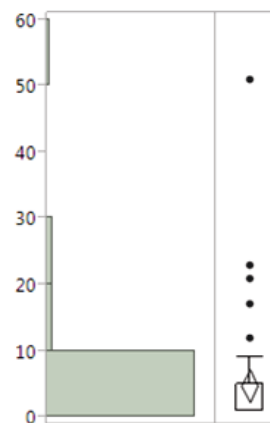


Table 14. HUD Activations: Condition B and Condition C

The images in Figure 44 and Figure 45 display the percentages of time that subjects kept the HUD deployed in both Condition B and C. In Condition B, subjects choose to keep the HUD up for 96% of the transit. In Condition C, subjects choose to keep the HUD deployed for 98% of the transit. We interpret this to mean the subjects felt very comfortable with having the HUD activated for the entire transit.

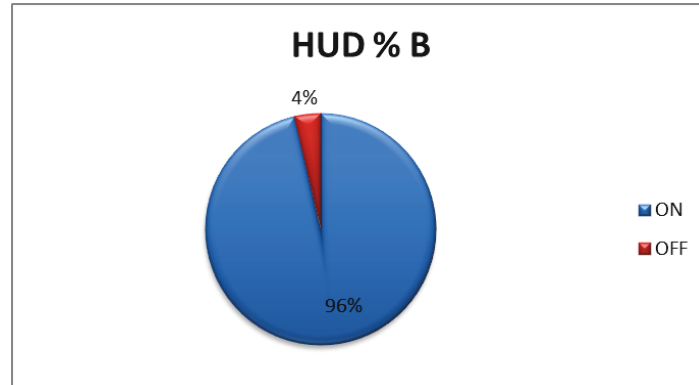


Figure 44. HUD Deployment Percentage: Condition B

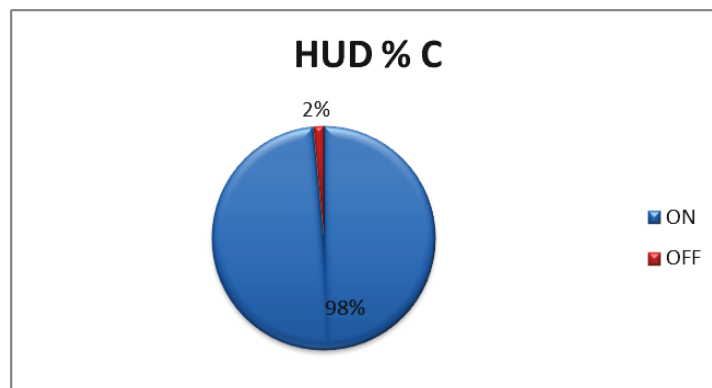


Figure 45. HUD Deployment Percentage: Condition C

The information in Table 15 indicates the distribution of number of times subjects chose to move within the ship's bridge. Of the 75 total sessions, the average number of transitions was 3.65 times per session with a standard deviation of 3.14 moves. The max number of moves was 12, and 9 subjects chose to not move at all.

Mean	3.6533333
Std Dev	3.1429601
Std Err Mean	0.3629178
Upper 95% Mean	4.3764628
Lower 95% Mean	2.9302039
N	75

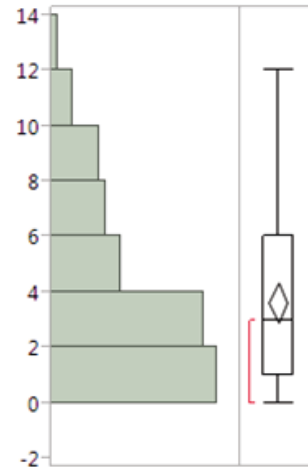


Table 15. Total Moves on the Bridge

The image in Figure 46 displays the aggregate distribution of where subjects chose to stand in the simulation through all sessions. The positions are labeled as follows: A (the left bridge wing), B (the left-center bridge), C (the right-center bridge), and D (the right bridge wing). Subjects spent the most time (36%) at the left-center bridge position. This is expected as that position was the starting position and several subjects choose not to move once the simulation began. The second position with the highest value (27%) is the right-center bridge. This indicates that subjects preferred to be inside while driving the ship. The best estimation of why this is the case is because the positions closest to centerline provided the easiest indicators of where the ships bow was actually pointing. The image in Figure 47 displays the distribution of the subjects' location per session. In each session, subjects spent the most time: 33% (Condition A), 36% (Condition B), and 38% (Condition C) at position B. At each position, there is only minor statistical variance per condition which indicates that the subjects' position on the bridge was not determined by their use of the HUD.

Bridge Location All Conditions

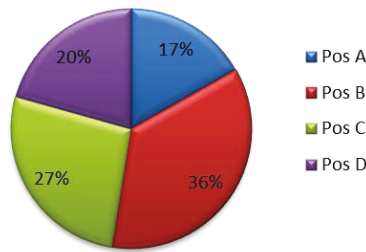


Figure 46. Distribution of the Subjects' Location on the Bridge: All Conditions

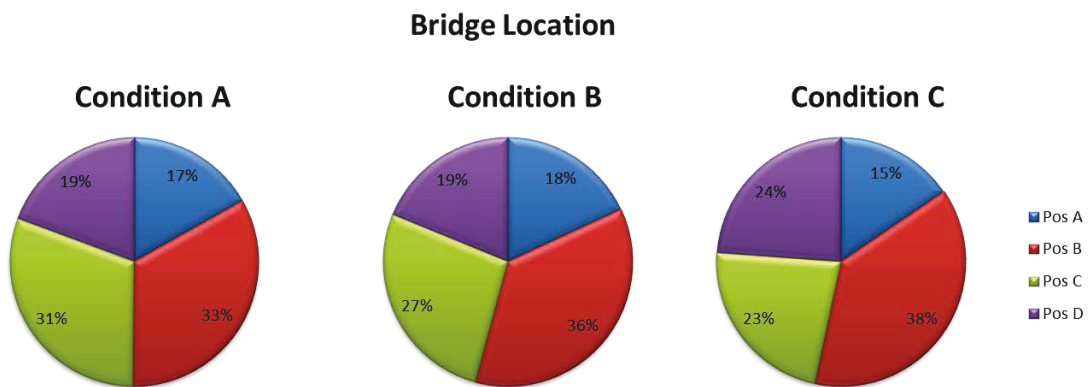


Figure 47. Distribution of the Subjects' Location on the Bridge: Individual Conditions

2. Subjective Data

We derived the data set presented and discussed in this section from the surveys that the subjects took after each session including a final questionnaire that was given after the final session. The final questionnaire asked the subjects to order the conditions in terms of usefulness for staying close to the centerline of track (Appendix E). Additionally, the final questionnaire asked for the subjects' opinions on the realism of the VE.

(1) Post Session Surveys

The information in Table 16, Table 17, and Table 18 present what subjects reported when asked how much of the time they felt they were on track (<10 yds off track) after each session. For Condition A, the subjects reported they felt they were on

track an average of 38.40% of the total transit time with a standard deviation of 19.08%. For Condition B, the subjects reported that they felt they were on track an average of 61.60% of the total transit time (st. dev. 22.30%). For Condition C, the subjects reported they felt they were on track an average of 64.00% of the total transit time (st. dev. 18.26%). This indicates that the subjects participating in conditions with the HUD felt they were on track for at least 20% more of the time than without the HUD. The objective data presented in the previous section verifies the subjects' opinions.

Mean	38.4
Std Dev	19.078784
Std Err Mean	3.8157568
Upper 95% Mean	46.275335
Lower 95% Mean	30.524665
N	25

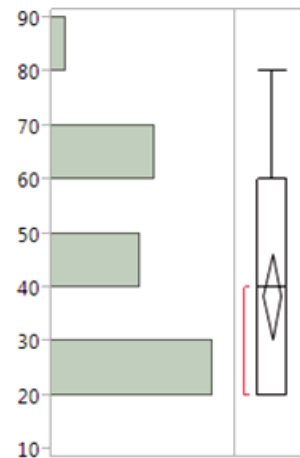


Table 16. Subject's Self-Estimation of Percent Time On-Track: Condition A

Mean	61.6
Std Dev	22.300972
Std Err Mean	4.4601943
Upper 95% Mean	70.805389
Lower 95% Mean	52.394611
N	25

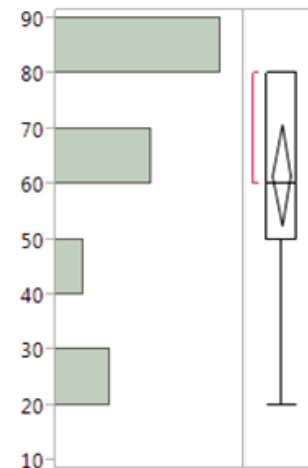


Table 17. Subject's Self-Estimation of Percent Time On-Track: Condition B

Mean	64
Std Dev	18.257419
Std Err Mean	3.6514837
Upper 95% Mean	71.536292
Lower 95% Mean	56.463708
N	25

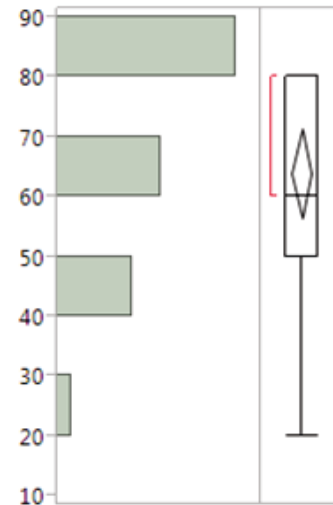


Table 18. Subject's Self-Estimation of Percent Time On-Track: Condition C

The information in Table 19 shows the distribution of reporting on the navigation evaluator's performance during Condition A and Condition B respectively. Condition C did not use the navigation evaluator. We asked the subjects to rate the following elements of the navigation report on a five-point Likert scale where one was "not at all well" and five was "very well": timeliness, clarity, and the content of the information. The most common report for all elements was a five. For the case of the study, this figure clearly illustrates the role of navigation evaluator was carried out successfully. Additionally, when asked if there was anything the subjects would recommend adding to the navigation report, several subjects provided the same recommendations. Out of the 50 surveys given between both conditions; 3 of 50 (6%) recommended adding the time until the next turn, 8 of 50 (16%) recommended adding a recommended course to regain track, and 4 of 50 (8%) recommended reporting if the ship was opening or closing onto track. The last information the opening or closing onto track - represents the standard way that navigation evaluators let the conning officer know if they ship is drifting away or drifting towards the center of the track. A breakdown of the response data can be found in Appendix L.

Navigation Evaluator Reports Evaluation			
	Average	Std. Dev.	Mode
Info was Timely: Condition A	4	1.08	5
Info was Timely: Condition B	3.92	0.99	5
Info was Loud and Clear: Condition A	4.52	0.87	5
Info was Loud and Clear: Condition B	4.44	0.77	5
Necesarry Info was Provided: Condition A	4.36	0.95	5
Necesarry Info was Provided: Condition B	4.16	0.94	5

Table 19. Evaluations of Navigation Evaluator Reports

The information in Table 20 shows the results of subject evaluations of the HUD components. We asked the subjects to rate the following elements of the HUD on a five-point Likert scale where one was “illegible” and five was “very legible”: legibility of the font, size of the font, contrast of the font. We asked the subjects to rate the ease of deployment on a five-point Likert scale where one “very difficult” and five was “very easy.” We asked the subjects to rate the level of distraction on a five-point Likert scale where one “very distracting” and five was “not distracting.” In both conditions B and C, the subjects rated all HUD elements above average. Additionally, we asked subjects to rate how helpful the HUD was during the transit on a five-point Likert scale, where one was “not helpful” and five was “very helpful.” Over 90% of the subjects reported a four or five, indicating that they found the HUD helpful. A breakdown of the response data can be found in Appendix L.

HUD Evaluation			
	Average	Std. Dev.	Mode
Level of Distraction: Condition B	4.04	0.93	4
Level of Distraction: Condition C	3.96	1.02	4,5
Legibility of Font: Condition B	4.32	0.90	5
Legibility of Font: Condition C	4.36	0.81	5
Size of Font: Condition B	4.44	0.71	5
Size of Font: Condition C	4.32	0.75	5
Contrast of Font: Condition B	4.40	0.72	5
Contrast of Font: Condition C	4.32	0.75	5
Ease of HUD deployment: Condition B	4.24	1.12	5
Ease of HUD deployment: Condition C	4.12	1.12	5
Helpfulness of HUD: Condition B	4.72	0.54	5
Helpfulness of HUD: Condition C	4.48	0.65	5

Table 20. Evaluations of the HUD Elements

When asked if the necessary information was provided in the HUD to accomplish their task, the subjects were presented a Likert scale where: one was “not enough information,” three was “enough information,” and five was “too much information.” The surveys indicated that 54% of the subjects reported having “enough information” (option 3) and that 94% of subjects selected options two, three, or four on the above scale. This indicates that the subjects were provided enough resources in the HUD to accomplish their task.

The information in Table 21 illustrates the breakdown of how subjects ranked the conditions and therefore the navigation information reporting methods. The question read as follows (APPENDIX E):

When you think back about your experience, how would you rank the experimental setups used for conning out of the channel? *Rank from one to three. One being the most useful for staying on track, three being the least.* [sessions to be ranked: Nav Eval Only (A), Nav Eval and HUD (B), or HUD only (C)]

Of the nine possible combinations of responses, only three orderings were reported. Three subjects (15%) ordered the setups as (1st: B, 2nd: A, 3rd: C), i.e., (1st: Nav Eval and HUD, 2nd: Nav Eval Only, 3rd: HUD only). Eight subjects (40%) ordered

the setups as (1st: B, 2nd: C, 3rd: A), i.e., (1st: Nav Eval and HUD, 2nd: HUD only, 3rd: Nav Eval Only). Nine of the subjects (45%) ordered the setups as (1st: C, 2nd: B, 3rd: A) (1st: HUD only, 2nd: Nav Eval and HUD, 3rd: Nav Eval Only). Of the 25 subjects, five did not report any order, but only selected one scenario. Of those, two subjects (8%) selected only B, (Nav Eval and HUD) and three subjects (12%) selected only C (HUD only).

Reviewing these reports, and those on the usefulness of the HUD, we find that the average reception of the HUD is significant enough to be able to make a determination of our secondary hypothesis. All 25 officers in the study rated one of two conditions that used HUD as their preferred choice they ranked condition B (Nav Eval and HUD), or condition C (HUD) as their 1st choice. Out of 20 subjects who ranked all three conditions, none of the subjects selected the condition A (Nav Eval) as their 1st choice; only 3 subjects selected it as their 2nd choice; and all other subjects selected it as their least preferred (3rd) choice. This confirms that the subjects found HUD to be useful for their task performance, suggesting their receptiveness to the idea of adding a HUD concept to their operations. We therefore conclude that surface warfare officers will be receptive toward the integration of a similar system in their daily operations.

- Alternate Hypothesis: H2_A The surface warfare officers will be receptive to the idea of integrating and using such a system into their daily operations

Order	Count	Prob
(B,A,C)	3	0.15000
(C,A,B)	8	0.40000
(C,B,A)	9	0.45000
Total	20	1.00000

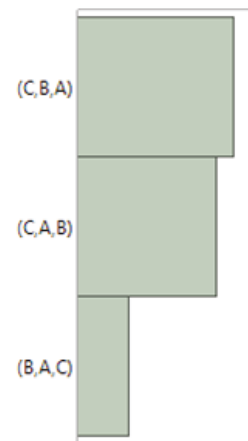


Table 21. Subjects' Preferred Conditions (Ordered Best to Worst)

The information in Table 22 shows the results of subject evaluations of the simulated environment. We asked the subjects to rate the following elements on a five-point Likert scale where one was “inaccurate” and five was “accurate”: ship’s motion physics, visual representation of objects internal to the ship, and visual representation of objects external to the ship. The most common report for each of these questions was a four. The average report for ship motion physics was 3.60 (st. dev. 0.82). The average report for visual representation of objects internal to the ship was 3.72 (st. dev. 0.89). The average report for visual representation of objects external to the ship was 3.60 (st. dev. 1.08). Additionally, we asked the subjects to rate how well the navigation system internal to the ship allowed them to perform the given task on a five-point Likert scale where one was “hindered performance” and five was “aided performance.” The average report for this question was 3.64 (st. dev. 1.08) with the mode being three. A breakdown of the response data can be found in Appendix L.

System Evaluation			
	Average	Std. Dev.	Mode
Ship Motion Physics	3.6	0.82	4
Visual Representation of objects inside the ship	3.72	0.89	4
Visual Representation of objects outside the ship	3.6	1.08	4
How well did the simulated movement (within the ship’s bridge) allow you to perform you task?	3.64	0.99	3

Table 22. Post-Experiment Evaluation of the VE

(2) SSQs

The information in Table 23 presents the results of data reported on subjects’ symptoms related to SSQs. There were 100 reports in all, a total of four SSQs per subject: one SSQ after the training session and then one SSQ after each of the three ship-driving sessions. For the most part, the subjects reported having no symptoms of any kind. Additionally, not a single subject reported having severe symptoms of any kind. The

most common symptoms were reports of slight: eye strain (31%), fatigue (23%), difficulty focusing (21%), and blurred vision (21%). Moderate symptoms were reported 21 times with difficulty focusing (6%), eye strain (5%), and dizziness with eyes closed (4%) being the most reported. Of the baseline SSQs, 11 of 25 subjects (44%) reported having some symptoms and of those there were only slight symptoms. The most common baseline reports were of slight: fatigue (28%), eye strain (20%), general discomfort (12%), and headache (12%). Other than what has been reported above, there were not significant differences from the baseline reports.

	None		Slight		Moderate		Severe	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
General discomfort	83	83.0%	16	16.0%	1	1.0%	0	0.0%
Fatigue	75	75.0%	23	23.0%	2	2.0%	0	0.0%
Headache	95	95.0%	5	5.0%	0	0.0%	0	0.0%
Eye strain	64	64.0%	31	31.0%	5	5.0%	0	0.0%
Difficulty focusing	73	73.0%	21	21.0%	6	6.0%	0	0.0%
Salivation increasing	99	99.0%	1	1.0%	0	0.0%	0	0.0%
Sweating	88	88.0%	12	12.0%	0	0.0%	0	0.0%
Nausea	92	92.0%	8	8.0%	0	0.0%	0	0.0%
Difficulty concentrating	92	92.0%	7	7.0%	1	1.0%	0	0.0%
"Fullness of the head"	91	91.0%	7	7.0%	2	2.0%	0	0.0%
Blurred vision	78	78.0%	21	21.0%	1	1.0%	0	0.0%
Dizziness with eyes open	89	89.0%	11	11.0%	0	0.0%	0	0.0%
Dizziness with eyes closed	92	92.0%	4	4.0%	4	4.0%	0	0.0%
Vertigo	96	96.0%	4	4.0%	0	0.0%	0	0.0%
Stomach awareness	93	93.0%	7	7.0%	0	0.0%	0	0.0%
Burping	97	97.0%	3	3.0%	0	0.0%	0	0.0%

Table 23. SSQ Results from Study

3. Post-Session Interviews

We conducted an interview with each of the 25 subjects after the completion of their third session. While we made every attempt to ask the same type of questions to each subject, in order to allow the subject to freely express their personal opinions of the experience, each interview had a segment that was unique to that subject. Given this fact, we also collected opinions on issues that subjects volunteered to provide themselves (not all subjects commented all issues, and so a standard statistical analysis is not applicable to this data set). The following text provides a breakdown of the more frequent responses received.

One of the most commonly shared opinions was that the shipboard experience was fairly realistic. Ten subjects cited that either the ships physics system or the overall simulator was good. The most common complaint against the system, shared by seven subjects, was that the ship handled too responsively. This meant that the subjects felt the ship turned far quicker (sharper) than expected. Two of the subjects reported the system to be competitive or “on-par” with the COVE simulator. Another topic that saw frequency in the responses was the area of moving around the bridge. Whereas four subjects reported that the four predetermined positions offered enough freedom of mobility, another four subjects would have liked to have had a centerline position available. Two subjects felt the movement from one position on the ship to another position was too slow.

When asked about the HUD, the most common opinion disclosed (five subjects) was that the subjects were able to clearly see “through” the augmented layer and still take in the visual information outside (3D environment representing the ship, water and terrain). Three subjects reported that the text font in augmented layer (HUD) was too big. This was an early realization of the design team; however, the size of the text was dictated by the low resolution of the HMD. Five subjects found the HUD to be distracting but two of those subjects claimed that it was only initially so.

Due to the networked nature of the simulation design there were, at times, slight differences in what the conning officer might have seen in the HUD and what the

navigation evaluator was reporting on aurally. Five of the subjects reported noticing the difference in what was being reported aurally and what they saw visually. Three subjects said they would have placed more trust in the HUD whilst two subjects claimed they would have put their trust in what they would hear from the navigation evaluator.

The most commonly answered question was what a user's preferred condition was. Eight of the subjects reported that they preferred the condition with only the HUD. 12 of the subjects reported that they preferred the condition with the navigation evaluator and the HUD. Four subjects reported being "comfortable" with the redundancy of having the navigation evaluator reports. Four subjects also reported feeling hesitant or bad about cutting off the navigation evaluator while he was making reports. The overall reporting in the interviews did not match the final questionnaire data when it came to preference of condition. A reason for this may be that, although subjects felt they performed better with only the HUD, they may simply have preferred having the navigation evaluator as well.

4. Behavioral

We monitored all 75 sessions for physical behavioral cues – we made video recording of all sessions (the camera view captured subjects as they were standing and moving in front of the workstation). While a few subjects displayed slight disorientation when first donning the headset, no subject exhibited the signs of mild or severe dizziness, fell, or injured themselves during the study. All cues of physical behaviors witnessed during the sessions were on par for what we would expect a real-world conning officer to display. There were no significant behavioral data to report on.

E. SUMMARY

This chapter discussed the user study and accompanying results. The data included information about subjects' demographics, performance data, self-reported data (surveys and interviews), and behavioral data (video recordings). The most important findings of the study were that subjects performed better when using the HUD. Additionally, the issues related to cognitive tunneling and cybersickness were minimal.

VI. CONCLUSION AND RECOMMENDATION

This chapter highlights the main contributions of the study and details future work that we see as viable within the domain. Whereas the study was initially proposed as a means of testing an operational concept onboard U.S. Navy ships, the end result has potential contributions to the fields of military research, VR, and AR. The chapter lays out guidance for the continuation of the work presented in this paper as well as recommended implementations of AR onboard Navy ships.

A. MAIN CONTRIBUTIONS

The work of this study contributes to the several domains. Firstly, in the domain of naval research, we have provided genuine data that illustrates the utility of integrating AR into the everyday operations of U.S. Naval personnel. Chapter V clearly lays out the numerical data that proves the statistical significance of the results gathered by the study. The analysis concludes that the use of the HUD made a positive difference in the subjects' performances (our first hypothesis). Additionally, through the subjective results, we witnessed a very high acceptance rate of the concept (our second hypothesis). This proof of concept for the use of an AR concept on the bridge of a ship applies to not only the navigation related displays but also real-world tactical displays. In essence, we have paved the way for further research that may equip the sailor of the future with AR heads up displays for numerous everyday operations.

In the general domain of military research, the work that went into designing and building the study is highly modular and can easily be duplicated in order to test AR hardware integration into a variety of operational settings. While displaying CNI was the primary focus of this study, the display of tactical information to Marines who act in an operational environment, or the display of improvised explosive devices to the bomb technicians are only slight modifications to the methodology. This study proves that, for minimal resources, these operational concepts can be tested in a safe and repeatable environment with negligible risk to the users.

In the domain of VR, this study represents one of the first research-based uses of an entirely new generation of inexpensive VR headsets (the Oculus Rift used in this study is one example of this line of products). What has started to become a phenomenon, the production of consumer based VR hardware is taking off. In only the past year, Oculus, Samsung, Sony, Zeiss Optics and HTC partnered with Valve/Steam have all created prototype VR hardware that they plan to bring to market soon. This work contributes to the field by taking great strains to precisely detail the processes needed to create a VE that is implementable on the new generation of hardware. With the entry price for VR becoming so low, many research projects outside the domain of computer science can now be accomplished in the safety of a VE. This work will contribute to that cause by being a great starting resource for those looking to build VR based studies.

This study has contributed to the domain of AR by not only finding a novel use for the technology in the military domain but also by modeling a method of testing AR concepts in a full VR simulation. As detailed in Chapter II, AR is not a new technology in the military domain; however, the NAVHUD system is a unique implementation of AR concept in the domain of shipboard navigation. The greater contribution to the AR domain is that we took an AR concept and rigorously tested it in a VR simulation. The reason this is a better route is that VR is faster and cheaper to program for; especially if control of the external environment is a critical factor. In this case, where the requirement would be to physically outfit a naval ship with the system (and to repeatedly navigate a predefined course) to test its usefulness, we can clearly demonstrate the immediate benefits of testing this AR system in VR.

B. FUTURE WORK

As this study was designed to test the operational usefulness of a HUD for conning officers, the most obvious future work would be a full-scale implementation of the system with real AR hardware integrated into the ship's current electronic navigation system. Of all the positive feedback that the concepts incorporated in this study have garnered, the most common recommendation given has been that this not be limited to navigation operations. Instead, many have recommended a large scale AR application

that integrates voyage management, radar systems, and weapon systems. The holistic adoption of AR onboard ships would benefit all departments from engineering to information systems. From shipboard firefighting to real-time missile tracking, there is room for AR in all naval domains.



On the smaller scale, the next practical step from this work would be to take the U.S. Navy's highest fidelity ship driving simulator, COVE, and test out an AR application similar to NAVHUD on it. Given the combination of the additional sensor data that is built into COVE, the validation of its physics system, and the hundreds of surface warfare officers who use the system every year; a large scale study (with COVE as the base platform) would provide indisputable data set on whether or not an AR system for conning officers is a viable option. If that proves successful, the next step would be going to a ship with an AR headset and really testing it in an operational environment.

C. SUMMARY

With 25 highly specialized subjects, nearly 20 hours of ship driving performance data, and hundreds of subjective data points; this study has been a great success. The results provided in Chapter V firmly suggest that a lightweight glasses-type AR overlay system for a conning officer will increase his ability to maintain a close proximity to a preplanned track. This chapter has discussed the many contributions that this work will provide to the domains of AR, VR, naval research, and military research in general. Finally, this chapter lays forth recommended continuations of this research, as well as similar veins of work that can be accomplished in the shipboard AR domain.

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APPENDIX A. RECRUITMENT POSTER



NAVHUD_2014

Naval Postgraduate School user study

TRY OUT THE NEXT GENERATION OF CONNING



Volunteer Conning Officers needed for research study.
Help us investigate a brand new way to drive ships

Your task will be very simple. You will:



- (1) Conn a ship in a virtual channel using the new Oculus Rift™
- (2) Be asked to reflect on your experience.

WHERE: SWOS, Building
and room TBD

HOW LONG: 1 x 90 min
or 2 x 45 min

WHEN: December 1st
through the 5th -
contact us to schedule
time (evening sessions
for students!)

WHO: Persons with
experience conning a
US naval vessel.



Please contact LT Brendan Geoghegan, USN bjgeoghe@nps.edu, 757-597-5131 to confirm your participation - give us several options for date(s) & time(s) when you will be available. For any amplifying information on the study please contact the Principal Investigator, Dr. Amela Sadagic, (831) 656-3819, asadagic@nps.edu.

This study is a part of research being conducted by the Naval Postgraduate School, Monterey California. Institutional review board (IRB) chair's contact information: Dr. Larry Shattuck, 831-656-2473, lshattu@nps.edu

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APPENDIX B. PRE-EXPERIMENT SURVEY

Page 1 of 4

Pre-Experiment Survey Questions:

Personal Background:

Q: What is your age? _____

Q: What is your sex? _____

Professional Background:

Q: Current Designation? _____

Q: Current rank? _____

Q: How many years do you have on active duty in the USN? _____


Q: How many years do you have you served as an 111X or 116X (SWO)?

Q: How long has it been since the last time you stood the watch of conning officer (years / months)?

Q: How long has it been since the last time you stood the watch of conning officer during a restricted water transit. (years / months)? Ex. Sea and Anchor.

Q: How many times have you have conned or served as OOD entering/leaving port. (Estimate).

Q: Have you ever been qualified as a Navigator or Navigation Evaluator?
☐Yes ☐No
If 'Yes' how long ago was it? _____ (years)



Q: Have you ever served on a fully ECDIS-N certified ship (IAW NAVDORM)?

☐ Yes ☐ No

If 'Yes' how long ago was it? _____ (years)

Q: How would you rate your current conning skill level?

Bottom 5% ☐ 50-35% ☐ 75-50% ☐ 95-75% ☐ Top 5% ☐

Environment Questions:

1) What types of video games do you play? What device do you use to play the games, and how often do you play them?

Do you play games at all?

- ☐ NO – go to question #2
- ☐ YES – answer the following questions:

Type of Game (check all that apply)	Devices (Check all that apply).	How often? (Check one and then enter your usage hours.)			
		Hours per day	Hours per week	Hours per month	Rarely
First Person Shooter <input type="radio"/>	I play them on (check all that apply): Computer <input type="checkbox"/> Smartphone <input type="checkbox"/> Tablet, Ipad <input type="checkbox"/> Game Console <input type="checkbox"/> Other Cellphone <input type="checkbox"/> E-Reader <input type="checkbox"/>	<input type="radio"/> Enter # of hours: _____	<input type="radio"/> Enter # of hours: _____	<input type="radio"/> Enter # of hours: _____	<input type="radio"/>
Online Multiplayer games <input type="radio"/>	I play them on (check all that apply): Computer <input type="checkbox"/> Smartphone <input type="checkbox"/> Tablet, Ipad <input type="checkbox"/> Game Console <input type="checkbox"/> Other Cellphone <input type="checkbox"/> E-Reader <input type="checkbox"/>	<input type="radio"/> Enter # of hours: _____	<input type="radio"/> Enter # of hours: _____	<input type="radio"/> Enter # of hours: _____	<input type="radio"/>
Adventure, Fantasy, Role Playing games <input type="radio"/>	I play them on (check all that apply): Computer <input type="checkbox"/> Smartphone <input type="checkbox"/> Tablet, Ipad <input type="checkbox"/> Game Console <input type="checkbox"/> Other Cellphone <input type="checkbox"/> E-Reader <input type="checkbox"/>	<input type="radio"/> Enter # of hours: _____	<input type="radio"/> Enter # of hours: _____	<input type="radio"/> Enter # of hours: _____	<input type="radio"/>

	I play them on (check <u>all</u> that apply):	Hours per day	Hours per week	Hours per month	Rarely
Other games <input type="radio"/>	Computer <input type="radio"/> Smartphone <input type="radio"/> Tablet, Ipad <input type="radio"/> Game Console <input type="radio"/> Other Cellphone <input type="radio"/> E-Reader <input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Enter the genre: _____		Enter # of hours: _____	Enter # of hours: _____	Enter # of hours: _____	

2) Were you **required** to use training simulations or simulators at any point in your career? (examples: COVE or Flight Sims.)

☐ Yes ☐ No

☐ NO – go to question #3

☐ YES – answer the following questions:

a. Enter the names of those simulations, what skills were they used to train, how many hours of training in total, and the date of last usage? Note*** If you do not remember the name of the simulation, then please enter its closest description instead.

1. Simulation #1: _____

Skills: _____

Total number of hours (approximate): _____

Date of last use (approximate): _____

2. Simulation #2: _____

Skills: _____

Total number of hours (approximate): _____

Date of last use (approximate): _____

3. Simulation #3: _____

Skills: _____

Total number of hours (approximate): _____

Date of last use (approximate): _____

4. Simulation #4: _____

Skills: _____

Total number of hours (approximate): _____

Date of last use (approximate): _____

3) Have you ever used a Head Mounted Display with motion tracking?

☐ Yes

☐ No

4) Have you ever used an augmented reality simulation? (ex. Google Glass, Aviation Helmet HUD)

☐ Yes

☐ No

APPENDIX C. CONSENT FORMS

A. IRB CONSENT

Page 1 of 2

**Naval Postgraduate School
Consent to Participate in Research**

Introduction. You are invited to participate in a research study conducted by the Naval Postgraduate School entitled Navigational Heads up Display (NAVHUD): will a shipboard augmented electronic navigation system sink or swim. The purpose of the research is to determine the viability of an operational setup of the bridge, onboard US Navy warships, in which a conning officer's visual field is augmented with an overlay of critical navigational information (CNI) that is typically relayed in aural form from the navigation officer.

Procedures.

You will be asked to run through a short virtual reality tutorial. You will then be briefed on a transit plan out of a channel. You will then command a ship out of a virtual channel using standard commands. Finally you will be asked to evaluate the heads up display system.

This study will take approximately one hour and thirty minutes.

You will perform the task alone. There will be a total of approximately 40 participants.

You will take part in three experimental sessions, one with a navigation evaluator, one with a navigation evaluator and a head's up display, and one with just the head's up display.

Your participation is helping acquire new understandings on use of heads up display technology in shipboard navigation.

Audio and video of your experience as well as a recording of your virtual experience will be taken for post experiment analysis.

Location. The interview/survey/experiment will take place in an office space in the International studies wing at the Surface Warfare Officer School, Newport RI or in an office space in Watkins Hall at Naval Postgraduate School, Monterey CA.

Cost. There is no cost to participate in this research study.

Voluntary Nature of the Study. Your participation in this study is strictly voluntary. If you choose to participate you can change your mind at any time and withdraw from the study. You will not be penalized in any way or lose any benefits to which you would otherwise be entitled if you choose not to participate in this study or to withdraw. The alternative to participating in the research is to not participate in the research.

Potential Risks and Discomforts. The potential risks of participating in this study are: *While every effort in the design of the virtual environment testing platform has been made to mitigate cyber sickness, there is a possibility the subject may have symptoms present during the study. Symptoms include visual symptoms (eyestrains, blurred vision, headaches), disorientation (vertigo, imbalance) and nausea (vomiting, dizziness).*

Anticipated Benefits. Anticipated benefits from this study are *the experiment will benefit the US Navy in terms of savings through reduction of errors, increased precision in execution of ship navigation, and a potential savings through reduced manning.* You will not directly benefit from your participation in this research.

Version #
Date:

➡

Compensation for Participation. No tangible compensation will be given.

Confidentiality & Privacy Act. Any information that is obtained during this study will be kept confidential to the full extent permitted by law. All efforts, within reason, will be made to keep your personal information in your research record confidential but total confidentiality cannot be guaranteed. No information will be publicly accessible which could identify me as a participant. You will be identified only as a code number on all research forms/data bases; your name on any signed document will not be paired with my code number in order to protect your identity. You understand that records of your participation will be maintained by NPS for ten years. However, it is possible that the researcher may be required to divulge information obtained in the course of this research to the subject's chain of command or other legal body.

Points of Contact. If you have any questions or comments about the research, or you experience an injury or have questions about any discomforts that you experience while taking part in this study please contact the Principal Investigator, *Dr. Amela Sadagic*, (831) 656-3819, asadagic@nps.edu. Questions about your rights as a research subject or any other concerns may be addressed to the Navy Postgraduate School IRB Chair, Dr. Larry Shattuck, 831-656-2473, lgshattu@nps.edu.

Statement of Consent. I have read the information provided above. I have been given the opportunity to ask questions and all the questions have been answered to my satisfaction. I have been provided a copy of this form for my records and I agree to participate in this study. I understand that by agreeing to participate in this research and signing this form, I do not waive any of my legal rights.

Participant's Signature

Date

Researcher's Signature

Date

Version #
Date:



B. AUDIO AND VISUAL CONSENT

Page 1 of 1

**Privacy act Statement and Consent Agreement
for Audio or Video Recording**

I have received a thorough description of the purpose and procedures for video recording during the course of the proposed research study. I give my consent to allow recording during participation in this study, and for those records to be reviewed by persons involved in the study, as well as used to produce a material (images or videos) that may be used to present the results of this study at conferences, in research papers and professional research meetings. I understand that all information will be kept confidential and will be reported in an anonymous fashion, and that the recordings will be erased five (5) years after the study has been completed. I further understand that I may withdraw this consent at any time without penalty.

Video recordings will be used to review physical cues of the subject while conning. These may include number of times the HUD is deployed, where the subject is preeminently looking, posture indications, simulator sickness symptoms, etc.

Audio recordings will be used to review aural cues such as conning officer / navigator interaction, misheard reports to the helm, number of commands given, etc.

<hr/> <div>Participant's Signature</div>	<hr/> <div>Date</div>
<hr/> <div>Researcher's Signature</div>	<hr/> <div>Date</div>

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APPENDIX D. SIMULATOR SICKNESS QUESTIONNAIRE

No _____

Date _____

SIMULATOR SICKNESS QUESTIONNAIRE

Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>
2. Fatigue	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>
3. Headache	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>
4. Eye strain	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>
5. Difficulty focusing	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>
6. Salivation increasing	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>
7. Sweating	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>
8. Nausea	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>
9. Difficulty concentrating	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>
10. « Fullness of the Head »	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>
11. Blurred vision	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>
12. Dizziness with eyes open	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>
13. Dizziness with eyes closed	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>
14. *Vertigo	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>
15. **Stomach awareness	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>
16. Burping	<u>None</u>	<u>Slight</u>	<u>Moderate</u>	<u>Severe</u>

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Last version : March 2013

***Original version : Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology*, 3(3), 203-220.

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APPENDIX E. EXPERIMENT SURVEYS

A. NAVIGATION EVALUATOR ONLY

Page 1 of 1

Performance Questions (Only the auditory Nav Eval inputs):

Q: How much of the time do you feel you were on track? (<10 yds off track)

20% of time	40%	60%	80%	100% of time
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Q: Looking back please evaluate the reports given by the Navigation Evaluator.

Information was timely:

1 (not at all well)	2	3 (average)	4	5 (very well)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Information was loud and clear:

1 (not at all well)	2	3 (average)	4	5 (very well)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Necessary information was provided for the task given:

1 (not at all well)	2	3 (average)	4	5 (very well)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Was there any additional reported information you would have liked to receive from the Navigation Evaluator?

B. NAVIGATION EVALUATOR AND HUD

Page 1 of 2

Performance Questions (HUD and Nav Eval):

Q: How much of the time do you feel you were on track? (<10 yds off track)

20% of time	40%	60%	80%	100% of time
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Q: Looking back please evaluate the reports given by the Navigation Evaluator.

Information was timely:

1 (not at all well)	2	3 (average)	4	5 (very well)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Information was loud and clear:

1 (not at all well)	2	3 (average)	4	5 (very well)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Necessary information was provided for the task given:

1 (not at all well)	2	3 (average)	4	5 (very well)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Was there any additional reported information you would have liked to receive from the Navigation Evaluator?

Q: Thinking back to your session, please evaluate the HUD (visual overlay consisting of the navigational information).

Level of distraction:

1 (very distracting)	2	3	4	5 (not distracting)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Legibility of the textual reports:

Font:

1 (illegible)	2	3 (average)	4	5 (very legible)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Size:

1 (illegible)	2	3 (average)	4	5 (very legible)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Contrast:

1 (illegible)	2	3 (average)	4	5 (very legible)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

➡

Necessary information was provided for the task given:

- | | | | | |
|-------------------------------|--------------------------|---------------------------|--------------------------|-----------------------------|
| 1 (not enough
information) | 2 | 3 (enough
information) | 4 | 5 (too much
information) |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

Ease of deployment of the HUD (Tapping the Hud):

- | | | | | |
|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 1 (very difficult) | 2 | 3 (average) | 4 | 5 (very easy) |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

How helpful was the HUD:

- | | | | | |
|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 1 (not helpful) | 2 | 3 (average) | 4 | 5 (very helpful) |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

C. HUD ONLY

Page 1 of 1

Performance Questions (HUD only):

Q: How much of the time do you feel you were on track? (<10 yds off track)

20% of time	40%	60%	80%	100% of time
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Q: Thinking back to your session, please evaluate the HUD (visual overlay consisting of the navigational information).

Level of distraction:

1 (very distracting)	2	3	4	5 (not distracting)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Legibility of the textual reports:

Font:

1 (illegible)	2	3 (average)	4	5 (very legible)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Size:

1 (illegible)	2	3 (average)	4	5 (very legible)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Contrast:

1 (illegible)	2	3 (average)	4	5 (very legible)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Necessary information was provided for the task given:

1 (not enough information)	2	3 (enough information)	4	5 (too much information)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Ease of deployment of the HUD (Tapping the Hud):

1 (very difficult)	2	3 (average)	4	5 (very easy)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

How helpful was the HUD:

1 (not helpful)	2	3 (average)	4	5 (very helpful)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

D. POST EXPERIMENT

Page 1 of 1

Post Experiment Survey:

Q: When you think back about your experience, how would you rank the experimental setups used for conning out of the channel? *Rank from one to three. One being the most useful for staying on track, three being the least.*

Nav Eval Only	Nav Eval and HUD	HUD only
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Q: How well did you feel the virtual environment accurately portrayed the experience of conning out of a harbor?

Ship motion physics were:

1 (not at all accurate)	2	3	4	5 (very accurate)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Visual representation of expected objects within the ship:

1 (not at all accurate)	2	3	4	5 (very accurate)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Visual representation of expected objects outside the ship:

1 (not at all accurate)	2	3	4	5 (very accurate)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

How well did the simulated movement (within the ship's bridge) allow you to perform your task?

1 (it hindered performance)	2	3 (it had no effect)	4	5 (it aided performance)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

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APPENDIX F. EXPERIMENT CHECKLIST

EXPERIMENT CHECKLIST:

SUBJECT ID _____

	Welcome the subject and thank them for participating
	IRB Informed Consent
	Audio/Visual Consent
	Pre-Experiment Survey
	Baseline SSQ (No. 1)
	Training Simulation
	SSQ (No. 2)
	Ship characteristics sheet (keep there)
	Instructions A/B/C
	Simulation A/B/C
	SSQ (No. 3)
	Instructions A/B/C
	Simulation A/B/C
	SSQ (No. 4)
	Instructions A/B/C
	Simulation A/B/C
	SSQ (No. 5)
	Post-Experiment Survey
	Debriefing Script
	Thank them for volunteering and offer them a chance at the other oculus.

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APPENDIX G. TASK INFORMATION SHEET

Page 1 of 1

Welcome,

You will be asked to conn a naval vessel out of a channel. Please review the following ship specifications and navigation plan for details of the transit. Once the simulation begins you will not have immediate access to this data, so please study it carefully. Feel free to ask any questions.

Vessel:

Length: 400 Ft:
Width: 60ft
Draft: 20 ft
Top Speed: 21 kts



Engine Orders:

(There will be no engine orders given; the ship will be set to travel at an average speed of 15 kts.)

Rudder Orders:

Any **standard** naval rudder commands can be used.

Feel free to drive by rudder or course.

Bridge Navigation:

Just as in your training tutorial, in order to move to different positions on the bridge you just need to ask the operator/helmsman to move you. You can move to left/right inner bridge and left/right bridgewings.

Transit Plan:

The following is a chart of the channel as well as planned course.

All turns calculated for standard rudder at 15 kts



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APPENDIX H. TASK INSTRUCTIONS

A. NAVIGATION EVALUATOR ONLY

Page 1 of 1

Instructions: (AUDIO ONLY)

We will assist you in putting on the head mounted display. When the simulation starts you will be placed at the left center of the bridge. The ship will be moving in the water at 15 knots heading in the direction of the first leg. As soon as you are ready to start, simply start giving commands to the helmsman and try **to drive as close to track as possible**. One of the performance metrics of this study is distance off track.

In this scenario you will be given the following aural reports by the Nav Eval:

Navigation Reports will be made coming out of turns and every minute after. Est. 3 reports per leg

- “I hold the ship XXX yard (left/right) out of the turn. Current speed is XX kts. Current course over ground is XXX. Distance to turn is XXX yds. Next course is XXX. At this time, Recommend (come (Right/Left) to regain track / maintain course and speed). – **out of the turn**
- “At time XXX, I hold the ship XXX yards (left of/right of/on) track. Current speed is XX kts. Current course over ground is XXX. Distance to turn is XXX yds. Next course is XXX. At this time, Recommend (come (Right/Left) to regain track / maintain course and speed).” –**Every minute in the turn**
- “200 yards till turn” –**at 200 yards to turn**
- “100 yards till turn” –**at 100 yards to turn**
- “Recommend come to course XXX” –**at turn**

Good Luck!

B. NAVIGATION EVALUATOR AND HUD

Page 1 of 2

Instructions: (AUDIO and VISUAL)

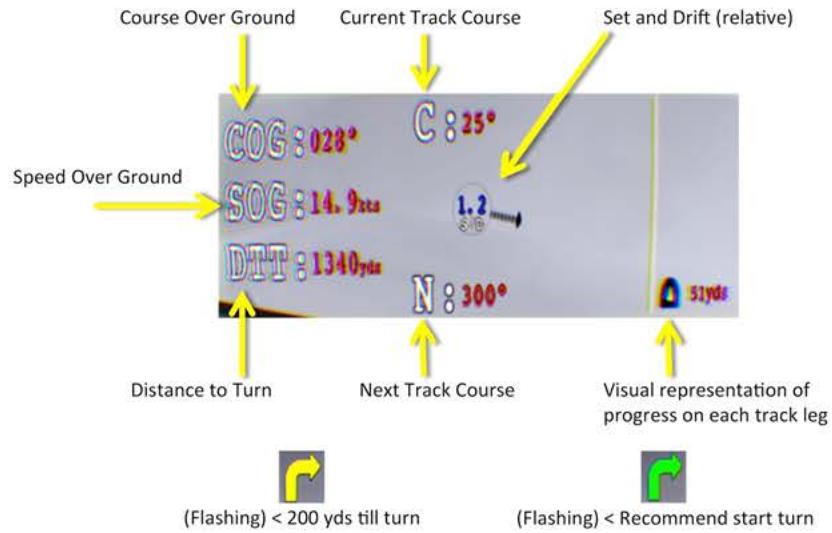
We will assist you in putting on the head mounted display. When the simulation starts you will be placed at the left center of the bridge. The ship will be moving in the water at 15 knots heading in the direction of the first leg. As soon as you are ready to start, simply start giving commands to the helmsman and **try to drive as close to track as possible**. One of the performance metrics of this study is distance off track.

In this scenario you will be given the following aural reports by the Nav Eval as well as be able to use a Heads Up Display:

Reports will be made coming out of turns and every minute after. Est. 3 reports per leg

- "I hold the ship XXX yard (left/right) out of the turn. Current speed is XX kts. Current course over ground is XXX. Distance to turn is XXX yds. Next course is XXX. At this time, Recommend (come (Right/Left) to regain track / maintain course and speed). – **out of the turn**
- "At time XXX, I hold the ship XXX yards (left of/right of/on) track. Current speed is XX kts. Current course over ground is XXX. Distance to turn is XXX yds. Next course is XXX. At this time, Recommend (come (Right/Left) to regain track / maintain course and speed)." – **Every minute in the turn**
- "200 yards till turn" – **at 200 yards to turn**
- "100 yards till turn" – **at 100 yards to turn**
- "Recommend come to course XXX" – **at turn**

The picture below is a sample of what your heads up display will look like. **In order to activate and deactivate the display, simply tap the headset with your finger.** (You may need to use a little force to get it to work)



Good Luck!

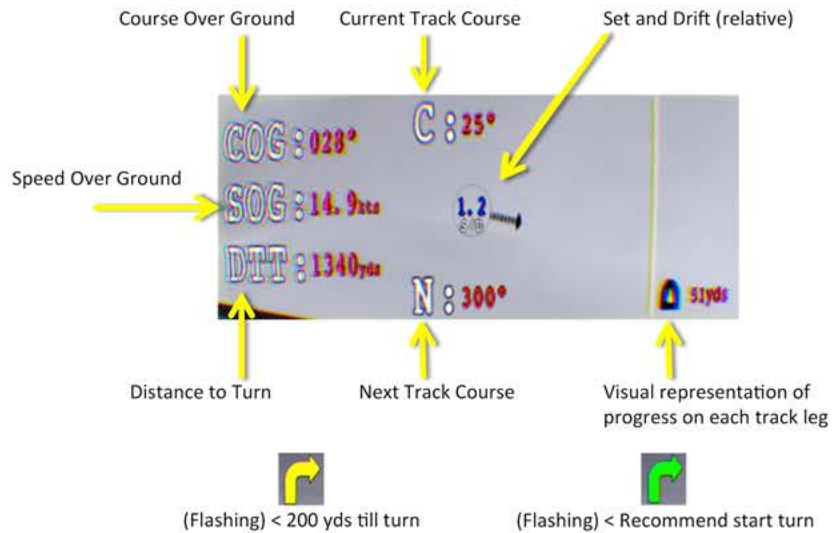
C. HUD ONLY

Instructions: (VISUAL ONLY)

We will assist you in putting on the head mounted display. When the simulation starts you will be placed at the left center of the bridge. The ship will be moving in the water at 15 knots heading in the direction of the first leg. As soon as you are ready to start, simply start giving commands to the helmsman and **try to drive as close to track as possible**. One of the performance metrics of this study is distance off track.

In this scenario you will be given only the ability to use the Heads Up Display:

The picture below is a sample of what your head's up display will look like. **In order to activate and deactivate the display, simply tap the headset with your finger.** (You may need to use a little force to get it to work)



Good Luck!

APPENDIX I. DEBRIEFING FORM

Page 1 of 1

Debriefing Form

Navigational Heads Up Display (NAVHUD)

Thank you for participating in this study!

While every effort in the design of the simulation has been made to mitigate cyber sickness, there is a possibility of you experiencing some symptoms temporarily during or after the study. Symptoms include visual symptoms (eyestrains, blurred vision, headaches), disorientation (vertigo, imbalance) and nausea (vomiting, dizziness). You are advised to refrain from following actions for 2 hours after the completion of your participation in the study: riding a bike, operating heavy machinery or climbing high structures. In case you experience a mild form of any of the symptoms, you are advised to sit down and rest. In case of severe forms of symptoms you are advised to seek the help of a medical professional.

If you are showing any symptom at this time we recommend you stay and allow us to observe you every 15 minutes until you are asymptomatic.

Points of Contact. If you have any questions or comments about the research, or you experience an injury or have questions about any discomforts that you experience while taking part in this study please contact the Principal Investigator, *Dr. Amela Sadagic*, (831) 656-3819, asadagic@nps.edu, Questions about your rights as a research subject or any other concerns may be addressed to the Navy Postgraduate School IRB Chair, Dr. Larry Shattuck, 831-656-2473, lgshattu@nps.edu.

Statement of Release (participant). I have read the information provided above. I have been given the opportunity to ask questions after my participation in the study, and all my questions have been answered to my satisfaction. I certify that at the time of signing this form I am symptom free.

Participant's Signature

Date

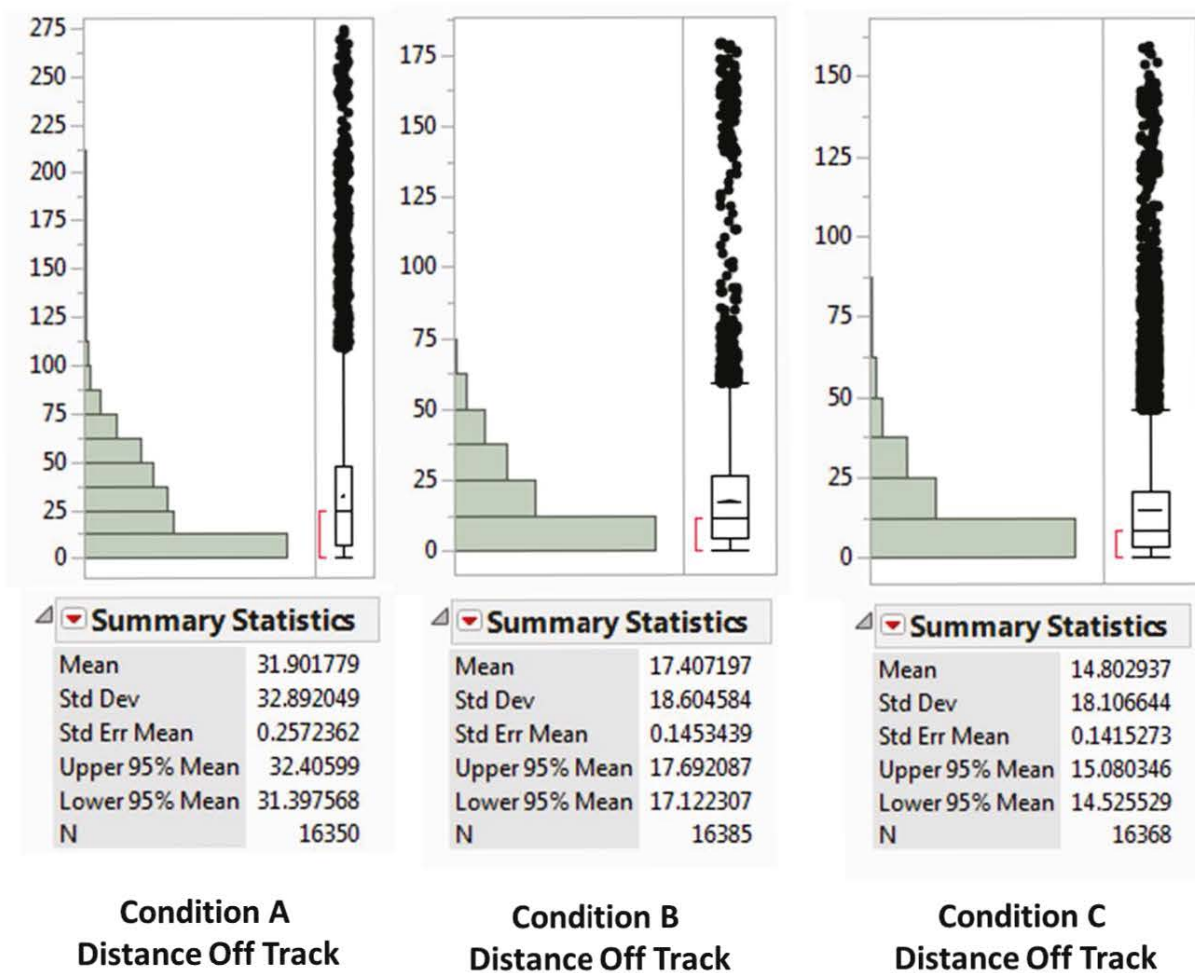
Statement of Release (researcher). I certify that at the time of signing this form the participant appears to be symptom free.

Researcher's Signature

Date

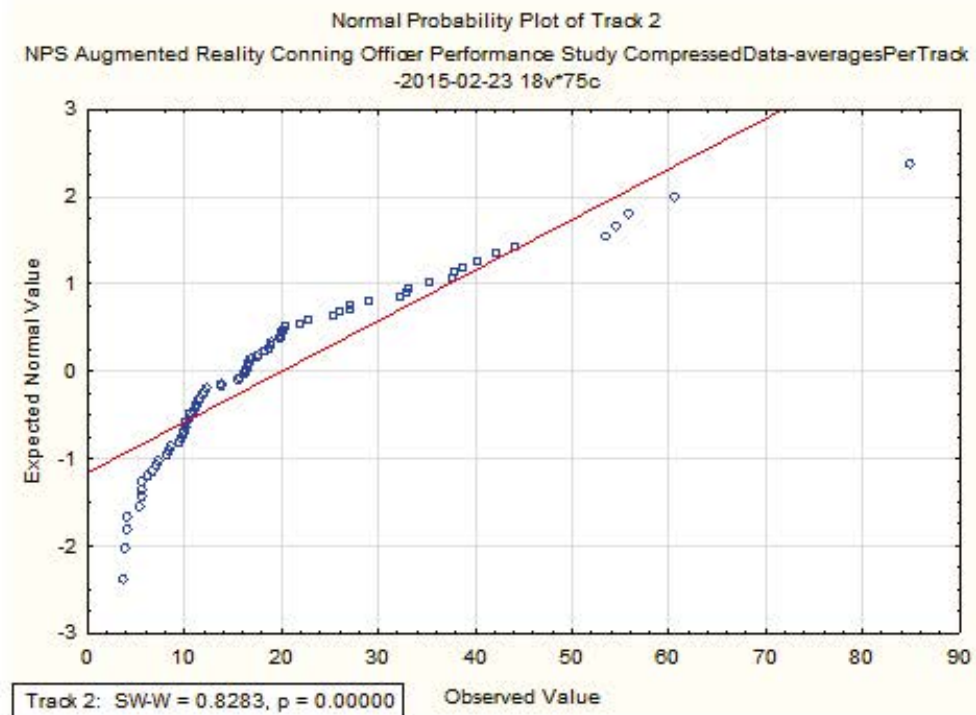
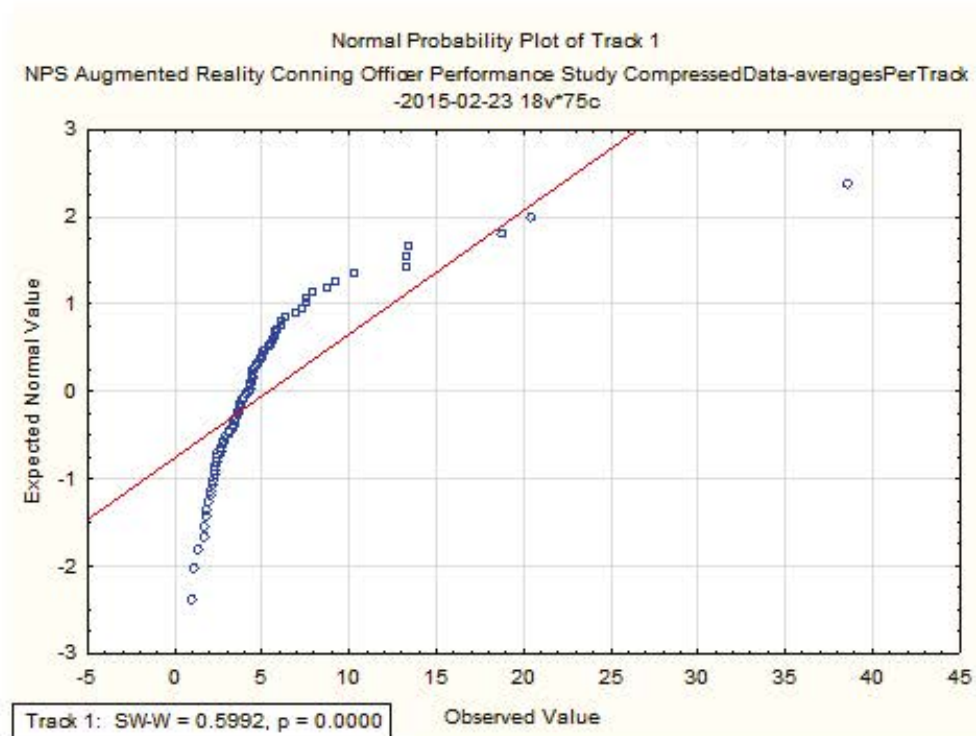
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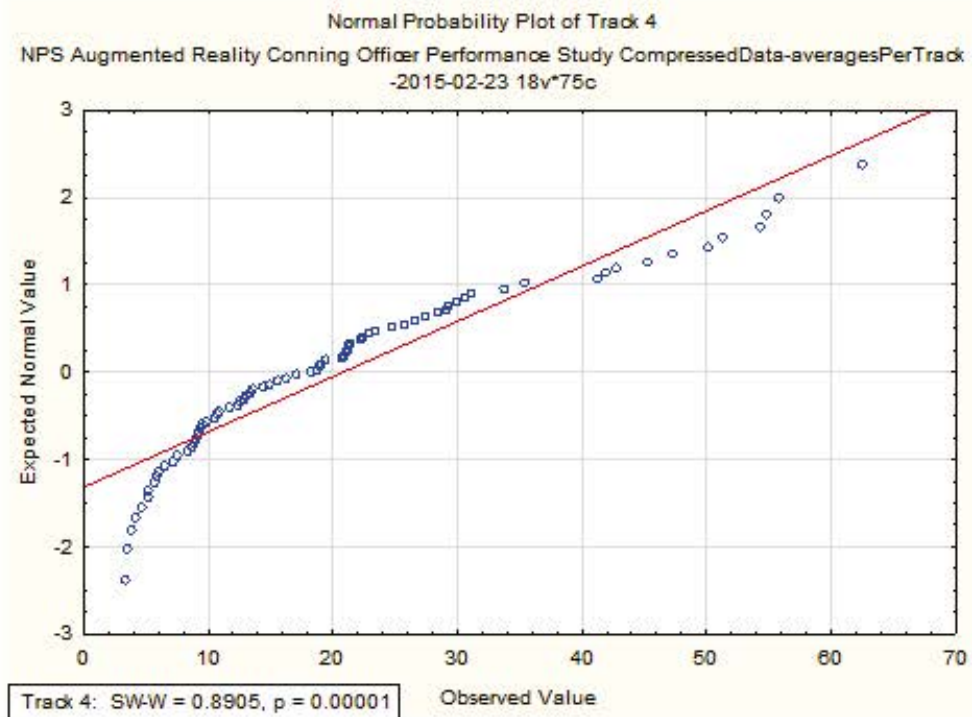
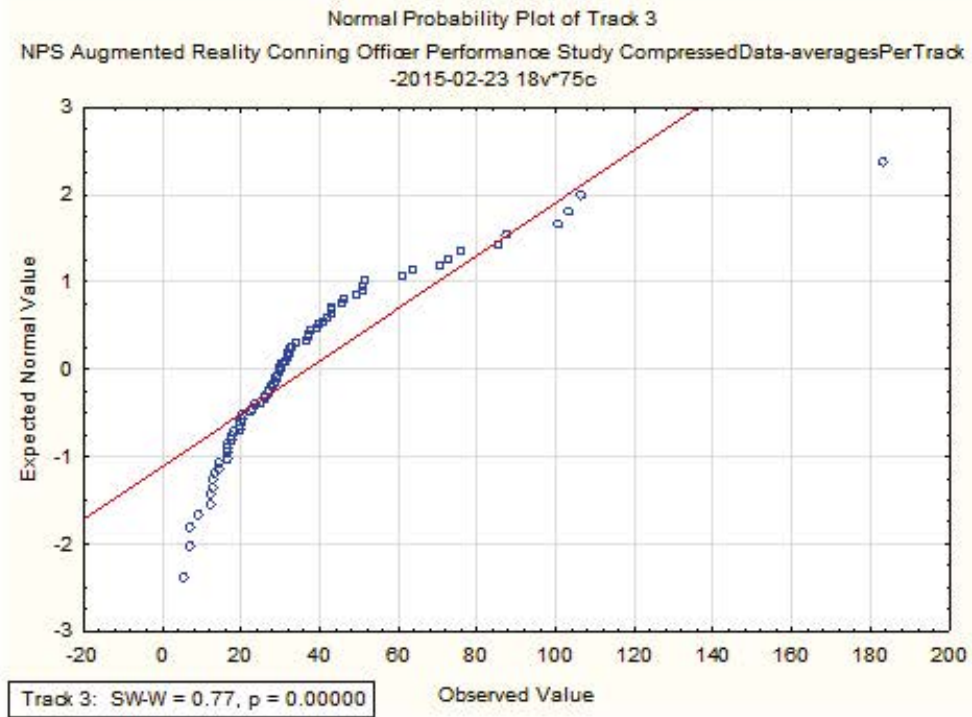
APPENDIX J. PERFORMANCE DISTRIBUTION DATA

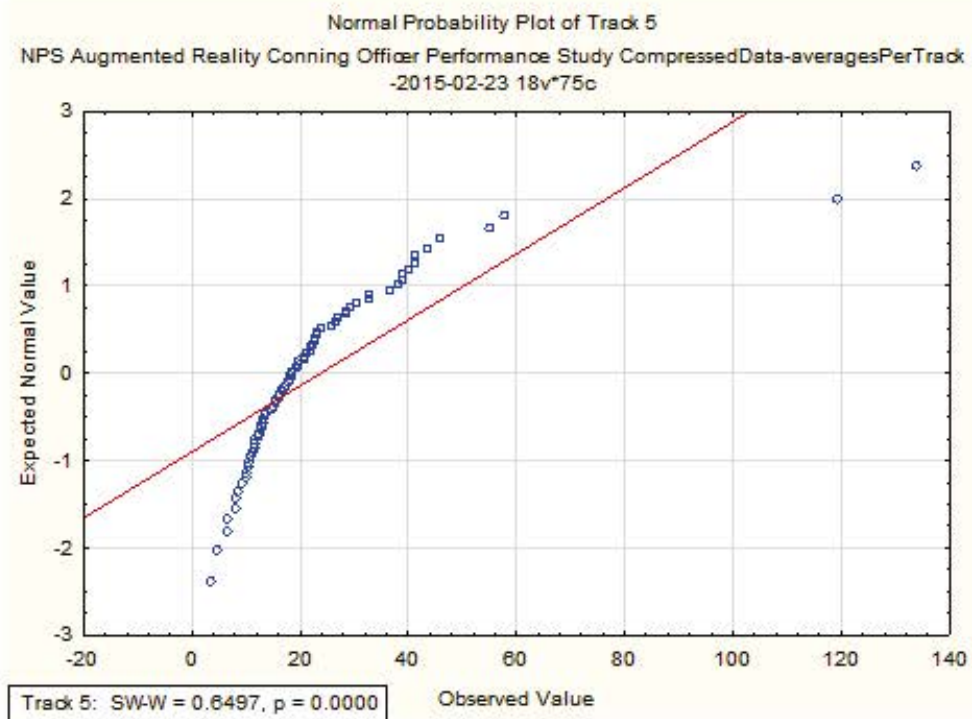


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APPENDIX K. PERFORMANCE DATA NORMALITY PLOTS.







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APPENDIX L. STUDY CONDITION EVALUATIONS

A. EVALUATIONS OF THE NAVIGATION REPORT (CONDITION A)

	1: Not at all well		2:		3: Average		4		5: Very Well	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Info was Timely	1	4.0%	0	0.0%	8	32.0%	5	20.0%	11	44.0%
Info Was Loud and Clear	0	0.0%	1	4.0%	3	12.0%	3	12.0%	18	72.0%
Necessary info was provided	0	0.0%	1	4.0%	5	20.0%	3	12.0%	16	64.0%

B. EVALUATIONS OF THE NAVIGATION REPORT (CONDITION B)

	1: Not at all		2:		3: Average		4		5: Very Well	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Info was Timely	0	0.0%	2	8.0%	7	28.0%	7	28.0%	9	36.0%
Info Was Loud and Clear	0	0.0%	0	0.0%	4	16.0%	6	24.0%	15	60.0%
Necessary info was provided	0	0.0%	1	4.0%	6	24.0%	6	24.0%	12	48.0%

C. EVALUTIONS OF THE HUD (CONDITION B)

	1: Illegible		2:		3: Average		4		5: Very Legible	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Legibility of Font	0	0.0%	1	4.0%	4	16.0%	6	24.0%	14	56.0%
Size of Font	0	0.0%	0	0.0%	3	12.0%	8	32.0%	14	56.0%
Contrast of Font	0	0.0%	0	0.0%	3	12.0%	9	36.0%	13	52.0%

	1: Very Distracting		2:		3:		4		5: Not Distracting	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Level of Distraction	0	0.0%	2	8.0%	4	16.0%	10	40.0%	9	36.0%

	1: Very Difficult		2:		3: Average		4		5: Very Easy	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Ease of HUD deployment	1	4.0%	1	4.0%	4	16.0%	4	16.0%	15	60.0%

	1: Not Helpful		2:		3: Average		4		5: Very Helpful	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Helpfulness of HUD	0	0.0%	0	0.0%	1	4.0%	5	20.0%	19	76.0%

D. EVALUTIONS OF THE HUD (CONDITION C)

	1: Illegible		2:		3: Average		4		5: Very Legible	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Legibility of Font	0	0.0%	0	0.0%	5	20.0%	6	24.0%	14	56.0%
Size of Font	0	0.0%	0	0.0%	4	16.0%	9	36.0%	12	48.0%
Contrast of Font	0	0.0%	0	0.0%	4	16.0%	9	36.0%	12	48.0%

	1: Very Distracting		2:		3:		4		5: Not Distracting	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Level of Distraction	0	0.0%	3	12.0%	4	16.0%	9	36.0%	9	36.0%

	1: Very Difficult		2:		3: Average		4		5: Very Easy	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Ease of HUD deployment	0	0.0%	3	12.0%	5	20.0%	3	12.0%	14	56.0%

	1: Not Helpful		2:		3: Average		4		5: Very Helpful	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Helpfulness of HUD	0	0.0%	0	0.0%	2	8.0%	9	36.0%	14	56.0%

E. POST-EXPERIMENT EVALUATIONS

	1: Inaccurate / Hindered performance		2:		3: Average / No Effect		4		5: Accurate / Aided performance	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Ship Motion Physics	0	0.0%	2	8.0%	9	36.0%	11	44.0%	3	12.0%
Visual Representation of objects inside the ship	0	0.0%	2	8.0%	8	32.0%	10	40.0%	5	20.0%
Visual Representation of objects outside the ship	0	0.0%	5	20.0%	6	24.0%	8	32.0%	6	24.0%

	1: Hindered performance		2:		3: No Effect		4		5: Aided performance	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
How well did the simulated movement (within the ship's bridge) allow you to perform you task?	1	4.0%	0	0.0%	12	48.0%	6	24.0%	6	24.0%

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